BURNETT

The Design of a Hydro-Electric Plant at Ottawa, Illinois

Electrical Engineering

B. S.

1914

THE DESIGN OF A HYDRO-ELECTRIC PLANT
AT
OTTAWA, ILLINOIS

BY

WILLIAM BURNETT JR.

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

ELECTRICAL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

1914 En

UNIVERSITY OF ILLINOIS

June 1, 1914

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

William Burnett Jr.

ENTITLED The Design of a Hydro-Electric Plant at

Ottawa, Illinois

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

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APPROVED: Ellery B. Paine.

HEAD OF DEPARTMENT OF Electrical Engineering

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Location.

The location of the development that is in hand is on the Illinois river about two miles below Ottawa Illinois. This river has a few fair sized tributaries consisting of the Fox river, Desplaines river and several small streams that empty into and drain this territory. In all the river system drains about 10,094 square miles. The surrounding country is of a very level nature after leaving the river banks. The ground has a very thin stratum of fine black soil about ten inches deep. Then comes a fine grade of sandstone. The sand stone layer is of very good quality and is on an average about thirty to forty feet deep. Under this is a layer of bed rock. This layer is about twenty feet deep and under this is a bed of hardpan.

The river bed is made up of gravel and sand stone. The gravel is on an average about three feet deep. Directly under this is a bed of sandstone. This is of the finest quartz type and of a white color. It is made of pebbles with very sharp edges and of uniform size.

This location makes it possible to sell power within a radius of 100 miles. The acessability to the railroads and the roadways is one of the great advantages that the plant possesses. The plant gives the employes the chance to live in a fair size town and the labor is easily obtained. Considering the proposition as a whole it looks as if the plant would be a money paying business and worth while to install.

The site of the dam is easy to get to, being just three miles from Ottawa, which is a town of about 10,000 people, and the railroad center for two railroads and the McKinley Traction system runs thru the town. The Burlington and the Rock Island railroads run within a half a mile of the power house. This gives facilities for obtaining material at any time and also means very little handling, because it can be transfered directly

to the McKinley tracks and taken right into the plant.

The Illinois river is fed from Lake Michigan and from the annual rain fall, on the surrounding country. The other small straems that flow into the river are about equally balanced on each side. The Desplaines river feeds out of the lake and the Fox river has its source up in the central part of Wisconsin. Below Lockport the Desplaines river is called the Illinois.

The available fall that can be had at Ottawa is 33 feet. The river at present is made up of three falls. The one at Ottawa has a drop of eleven feet, the one at Marseilles twelve feet and the one at Morris about ten feet. This makes 33 feet in all and if the water is raised to this height at Ottawa then the water levelwill bethe same back as far as Morris Illinois. This development is one that is termed a low head installation at the same time the head is not so low that a drop of two or three feet in the height of the water will cause trouble. The reservoir that can be had due to this head is nearly 35 miles long and about .3 of a mile wide. The nature of the river bottom is rather marshy composed of wet sandy soil. However there are places which will be flooded that contain very expensive land. These lands are being used for farming and the cost of this ground and the small islands that will be flooded is going to be one of the biggest items of expense. Of all the land that will be over-flowed it might be well to metion that .2 of it will be worth about $200.00 and acre. The goverment however listed it at $100.00 in 1903. The rest is valued about $125.00 and acre, but the goverment said that this could be bought for $50.00 an acre. This data was obtained from the United States Army Engineers who reported on the cost of the deep water way proposition.

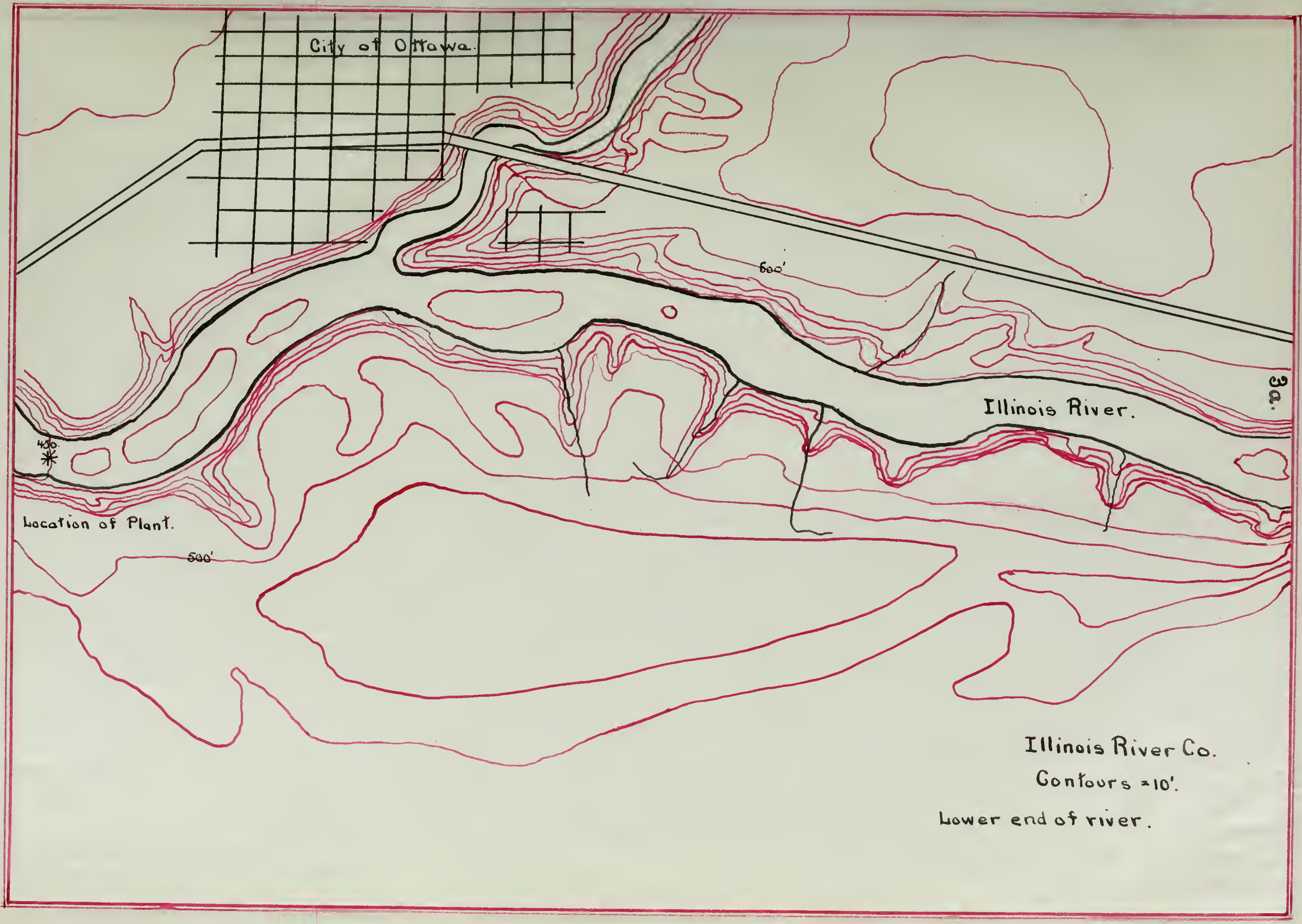
The elevation of Ottawa is 48.638 feet below the Hennepin datum and 103.656 feet below the Chicago datum. The distance from the main

source of the river to its mouth is four-hundred and fifty miles. This takes into account just the main river and does not include its tributaries.

The necessary data for the development of this plant was obtained from the United States Goverment. The topography as shown on page #3a which they send out shows that a dam can be placed at the purposed site and the river raised to a height of 33 feet. The land that will be rendered useless is about seven and fifty one hundredths square miles. This estimate is as exact as possible considering the fact that no specific data has been taken on the project and that this cost dertermines to a great extent wether the installation will pay or not. In order to get very exact results it would be necessary to have a very complete survey of the ground flooded. It would be necessary to study the condition of the ground and find where it would be possible to place small retaining walls instead of flooding large areas of land. The assumption that the United States enginners made was that land could be bought for $100.00 an acre and if this is true it can be used for a basis and the total overflow land would bost $481,000.00. This estimate is very low however and the cost will be based on costs obtained from the McKinley System on land that was bought for the Marseilles plant. As to the islands some of then would be entirely submerged when the river is raised but will affect the banks very little.

The present development will in no way interfere with the work of the deep water way proposal. It would rather help things and the goverment would have all to gain and nothing to lose, because of this installation.

The present installation of the McKinley people at Marseilles however must be moved down the river to the proposed site. Some of the machinery can be used in the new plant and part of it will have to be sold to plants operating under an eleven foot head. It is very possible



3a.
City of Ottawa.
Illinois River.
600'
500'
450.
Location of Plant.
Illinois River Co.
Contours = 10'.
Lower end of river.

that the 2500 kilo-watt unit outfit that is being used can be so arranged as to be installed as an exciter for one of the large generators at the new plant. At least the turbines could be used, the only difference being that they would operate at a higher speed. The idea for the moving of the old plant is that it has an auxillary steam plant in connection with it and of course this makes it very expensive. At the times of the year when the river is low and the supply of the river is not great enough to operate,the steam power is used. Now the new plant will not have to have an auxillary steam plant,because an extra unit will be installed so that during the heavy load in the winter time it will be put into use,but during the light load months that come in the summer it can stand idle or be used as a reserve unit.

The location of this plant at this site has many points in its favor;

1st. At this postion in the river the shortest dam can be utilized. This is a great saving in the expense and time. There are high bluffs on each side of the river and this gives good conditions for anchoring the dam. The bluffs are composed of rather hard sandstone and there will be very little possibilty of the water leaking by,under the pressure exerted by the head of 33 feet.

2nd. The water power has to be utilized where it can be had. By this is meant the plant has to be located where the required head can be obtained and at the same time not floodtoo much valuable land. It is possible in many cases to conduct the water to the plant thru penstocks but this is very expensive first in installation and in up keep. In a fairly level country such as this the penstock proposition is one that is entirely out of the question because it is impossible to gain any head by their installation.

3rd. The geological conditions of theground at this location are of great

value in construction. All the gravel that is needed for the job can be obtained directly from the bed of the river. It is of the type that makes good concrete, because it has sharp edges and is of uniform size. At Marseilles all the crushed stone that will be needed can be had very cheap. It is a very good quality limestone. This can be transported to the job by railroads at very little expense. One of the other satisfactory things in this development is that a good foundation can be had. Within four feet of the present bottom of the river there is a bed of hard sandstone. Directly below this is a firm resting place for the dam on a bed rock foundation. By excavating down to this bed rock a very strong anchorage for the dam can be obtained. This of course is the one of the most important points in the design and it is very seldom that there are not some bad conditions to be met with before the work is completed. From the existing conditions there will be very little trouble in the work and therefore it should be completed at very low cost.

4th. The rainfall in this part of the country is very constant for each year, that is, it has it low water and its high water periods just about the same time each year, and the conditions that are to be met can be prepared for. Radical changes are not apt to come about, and this is a thing that can not be said for other sections of the country.

The evaporation in this part of the country is rather excessive during the year. Later the evaporation will be calculated theorically and then this result will be compared with that of the actual results between the years 1884 and 1904.

Calculation for Evaporation.

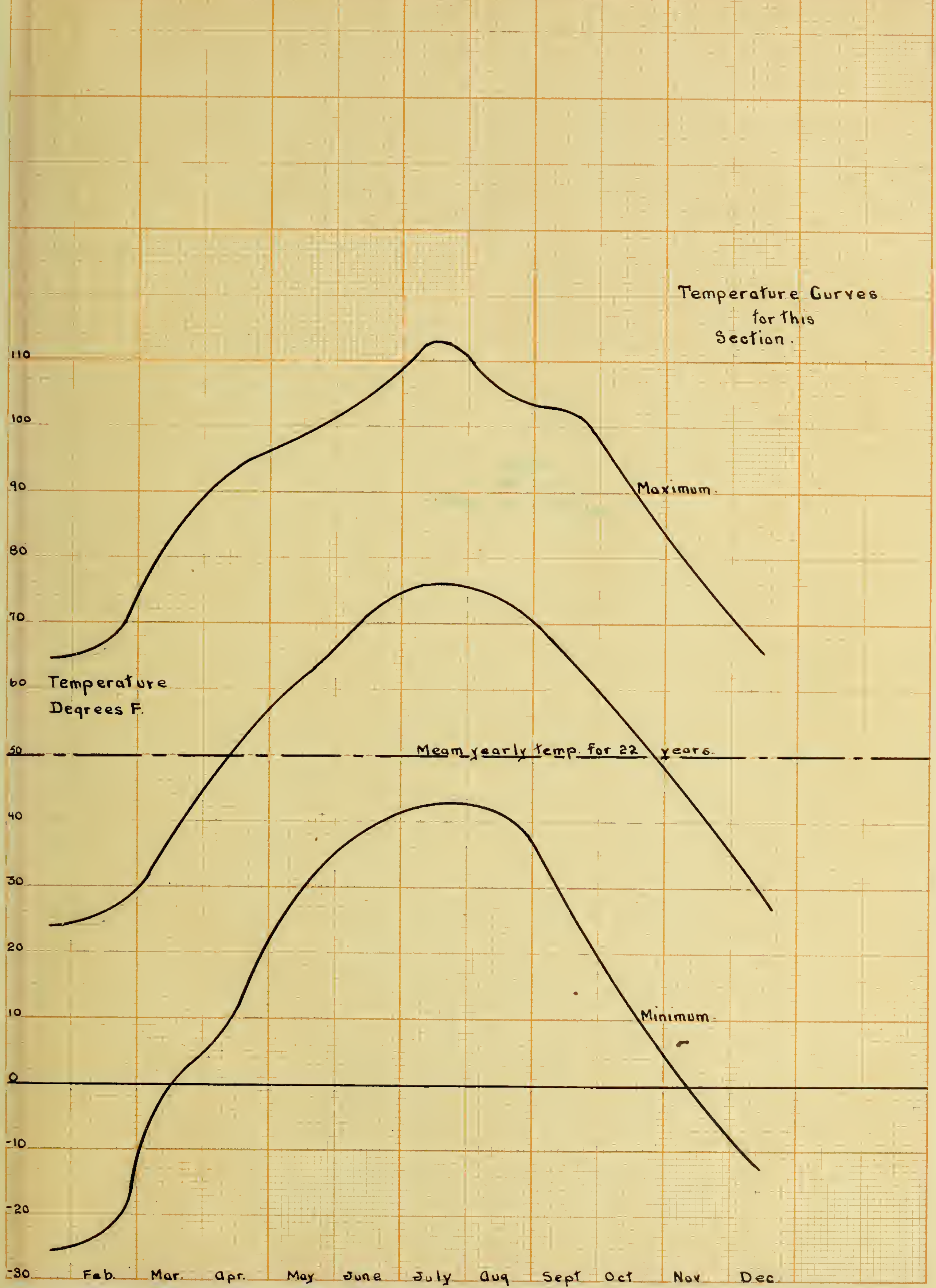
By means of Vermueles formulae, $E\ (15.5 + .16R)(.5T - 1.48) = 21.5$ in.

Where,

T = is the mean annual temperatuee in degrees F. 50°.

R = is the annual rainfall in inches 35.2 inches.

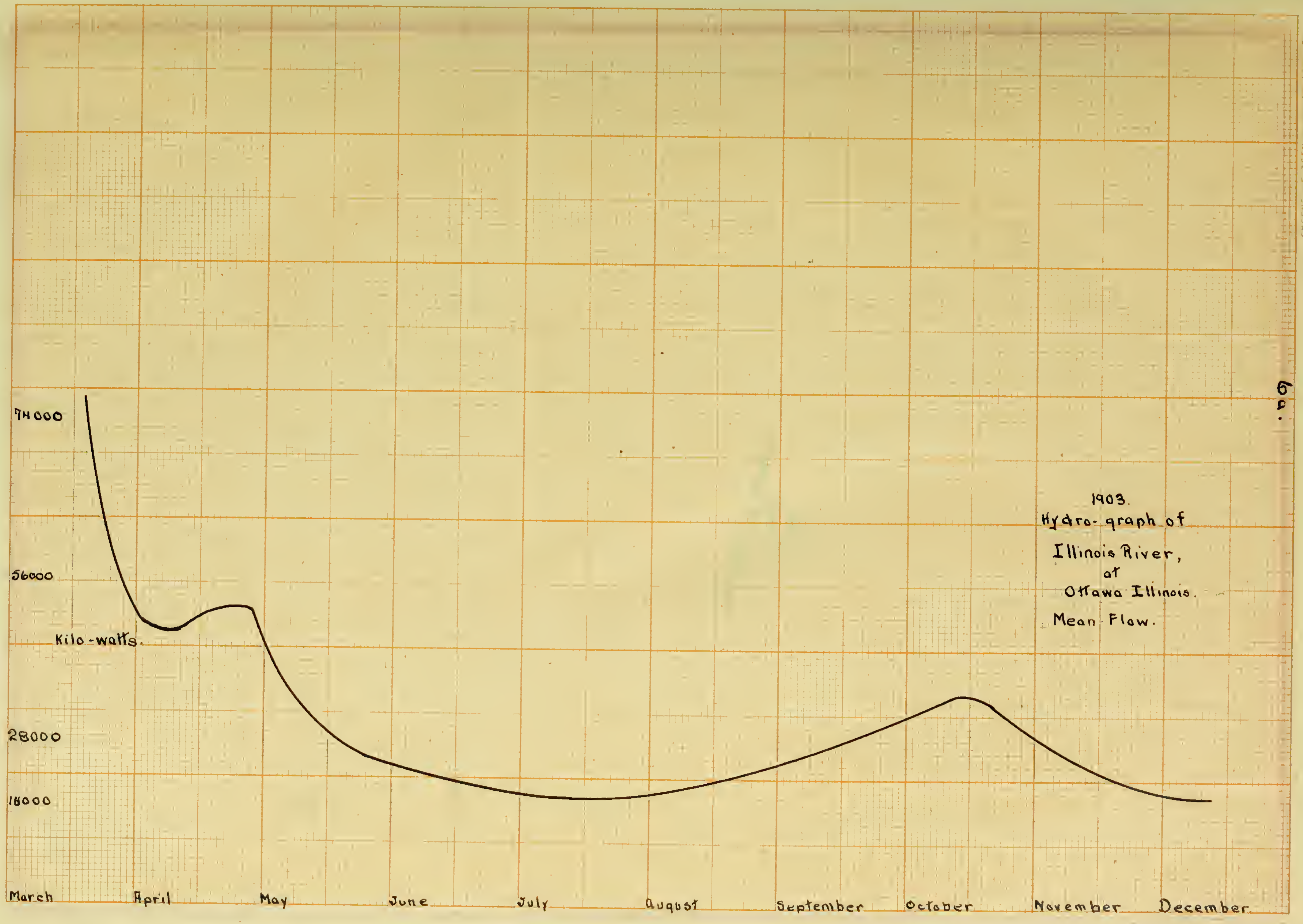
Then $35.2 - 21.5 = 13.7$ inches or the annual runoff from this territory.

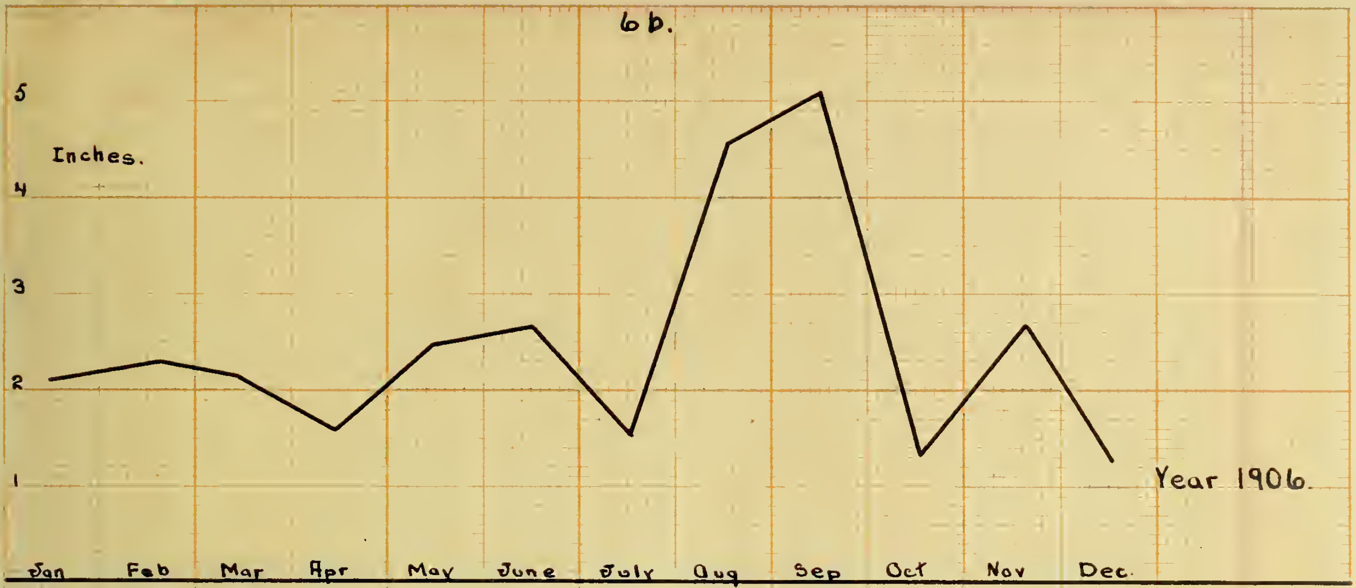

Temperature Curves
for this
Section.
110
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
Temperature
Degrees F.
Maximum.
Mean yearly temp. for 22 years.
Minimum.
Feb.
Mar.
Apr.
May
June
July
Aug
Sept
Oct
Nov
Dec

Rainfall.

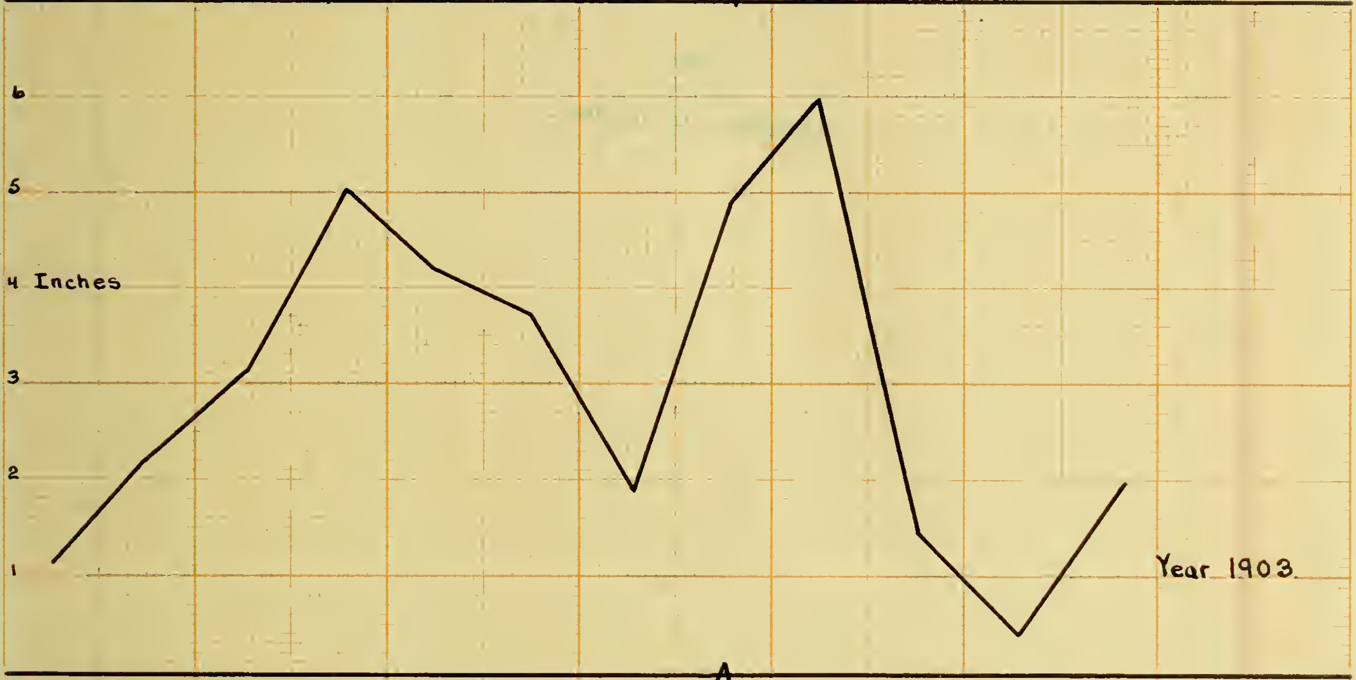
At Ottawa Illinois the goverment has kept a station for several years. The gage height of the river has been recorded, thereby giving the calculations for discharge. If the cross sectional area of the river is known then the discharge and the velocity can be calculated. The goverment data gives values for the amount of run-off per square mile and also the depth of the run-off in inches for the different months of the year. Thru out this part of the country the mean annual run-off is from ten to fifteen inches per year. In the foregoing pages on location the evaporation of this part of the country was calculated. It was found that the annual evaporation was about 21.5 inches and that of the runoff was something over 13 inches.

The most extensive data was taken by the United States in the year 1903. Most of the calculations for this design were based on the data obtained during this year. Since the rainfall is practically the same for all the years that have been recorded, and the climatic conditions have varied but little, there is no reason why the assumptions that are made here are not good for all the years to come. From these reports the hydrograph can be drawn for the year of 1903, and other curves can be drawn that will enable us to get the discharge for any gage height. Also a curve can be plotted that will show the output of the river in kilo-watts for the different months of the year. From the reports it is found that the minimum amount of water that has ever flowed by this section is 6700 cubic feet per second or if this condition should ever occur again, it must be looked out for and the plant constructed to meet this. Since the drainage district plant was installed the minimum flow is nearly 10,000 cubic feet per second the year around. On page #7 is shown some of the data that was taken form the deep water way papers.

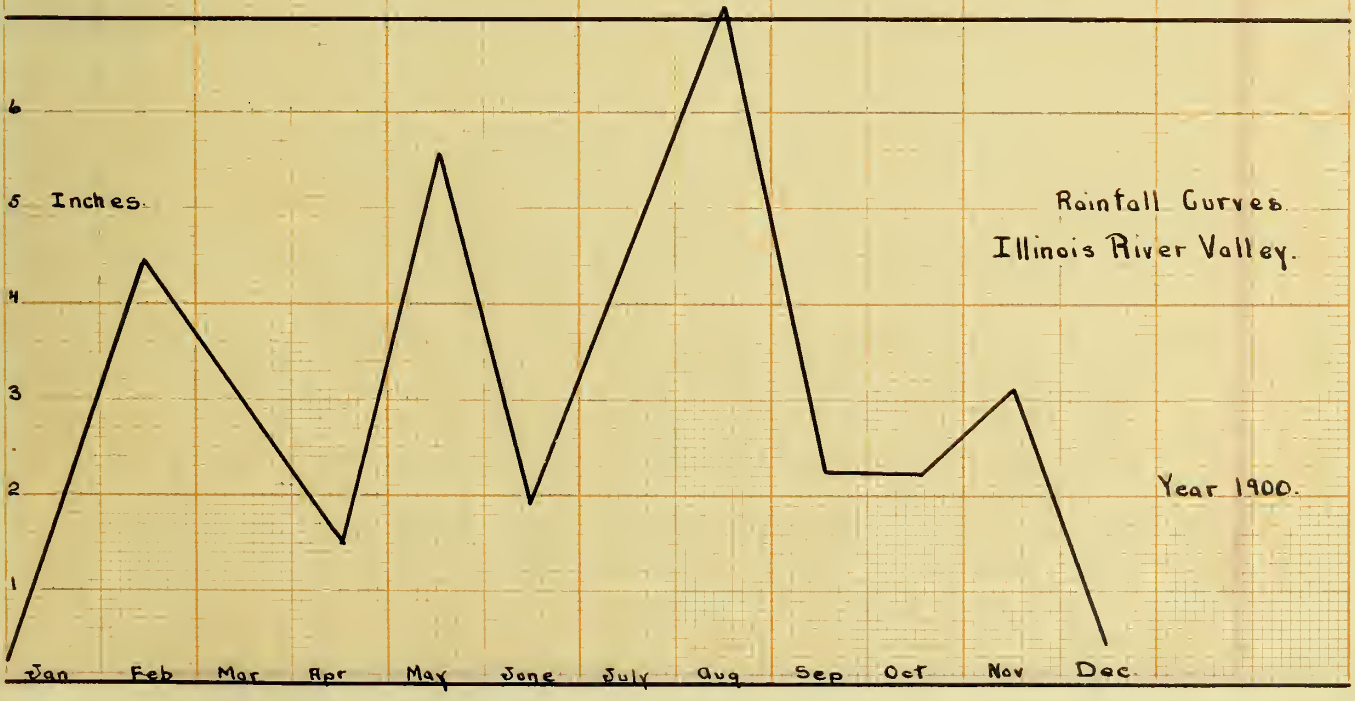

1903.
Hydro-graph of
Illinois River,
at
Ottawa Illinois.
Mean Flow.
Kilo-watts.
74000
56000
28000
18000
March
April
May
June
July
August
September
October
November
December.



5
Inches.
4
3
2
1
Year 1906.
Jan
Feb
Mar
Apr
May
June
July
Aug
Sep
Oct
Nov
Dec.



6
5
4 Inches
3
2
1
Year 1903.



6
5 Inches.
4
3
2
1
Rainfall Curves.
Illinois River Valley.
Year 1900.
Jan
Feb
Mar
Apr
May
June
July
Aug
Sep
Oct
Nov
Dec.

It is well to state here that the reports of the goverment are made up with extereme accuracy and all the data was taken by methods that are the best known. On page #7a there is a profile view of the bed in the Illinois river.

Data.

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	July.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual.
1900	1.60	4.53	2.91	1.53	5.60	1.96	4.53	7.24	2.26	2.24	3.16	.31	37.87
1901	1.76	2.10	3.51	..66	2.15	2.67	5.47	.81	3.20	.91	1.49	2.09	26.77
1902	.63	1.41	4.89	2.55	5.64	10.5	10.4	4.40	6,67	1.87	4.29	2.01	55.45
1903	1.13	2.35	3.10	5.08	4.19	3.78	1.94	4.90	6.03	1.43	.46	1.91	.36.30
1904	2.54	1.80	4.87	3.93	3.00	1.89	5.14	7.58	3.27	.26	.08	1.86	[illegible]
1905	1.30	1.93	2.09	5.15	3.68	3.39	1.69	4.12	2.13	1.87	2.01	1.70	31.05
1906	2.07	2.26	2.02	1.63	2.87	2.64	1.45	4.57	5.09	1.23	2.63	[illegible]	29.18
1907	5.25	.15	2.55	2.69	4.84	2.50	6.92	4.49	4.94	1.00	1.06	1.79	39.08
1908	.86	1.53	3.87	3.49	8.17	2.77	3.05	2.03	.35	.65	1.76	.99	28.54

Average snow-fall for 19 years,at Ottawa.

19 yrs.	8.0	8.9	4.5	.4	T	C	0	0	0	T	2.3	3.8	27.9

Mean temperature at Ottawa for 22 years.

	24	24.4	37	50.6	61.4	70.9	75.[illegible]	72.[illegible]	65.[illegible]	53.2	30	29.2	50

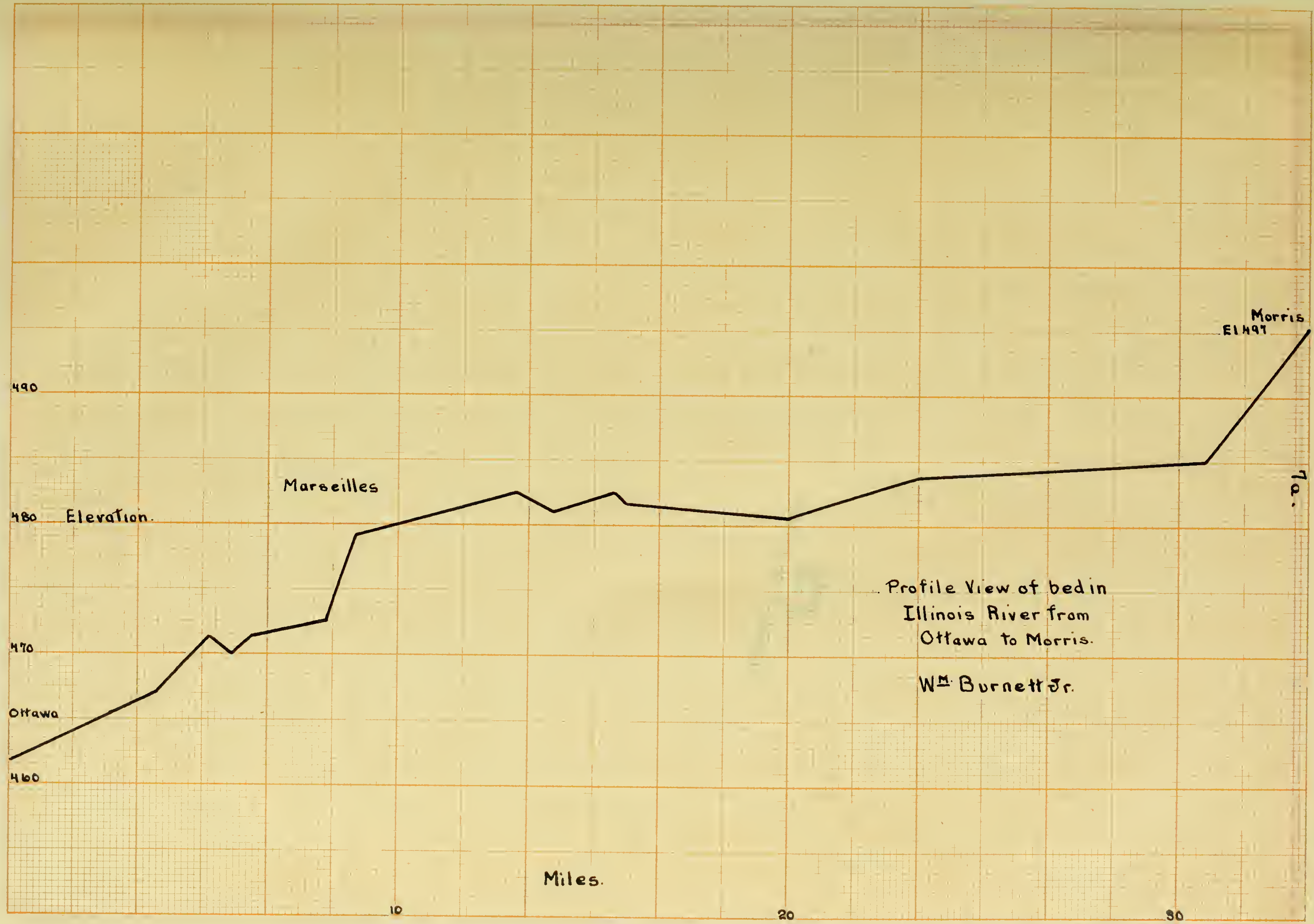
Lowest temperature at Ottawa for 21 years.

	-26	-24	-2	12	24	37	42	42	26	13	-4	-14	-2[illegible]

Highest temperature at Ottawa for 21 years.

	65	65	83	92	99	103	112	103	10[illegible]	90	76	6[illegible]	112

The yearly rainfall is one of the most important items in the development of a hydro-electric plant. The rain fall of course controls the yearly runoff and the discharge of the river. Data for the rainfall in the years of 1900,1903 and 1908. The curve that is drawn for the year 1903 is the one that will be used in calculations. The maximum rainfall comes in the months of June and July. At this time very heavy floods are apt to occur. It would seem that the river would be at its highest inthe fall of the year but thru out all the records that have been taken this is not the case. However the river comes up to the same height in the fall that it does in the foregoing months but this lasts only for a few hours.In June 1902,10.51 inches of rain was recorded,while for the same month 1905 only 3.39 inches of rain fell. It may also be noted that for the year 1902 in June the greatest amount of rain fell

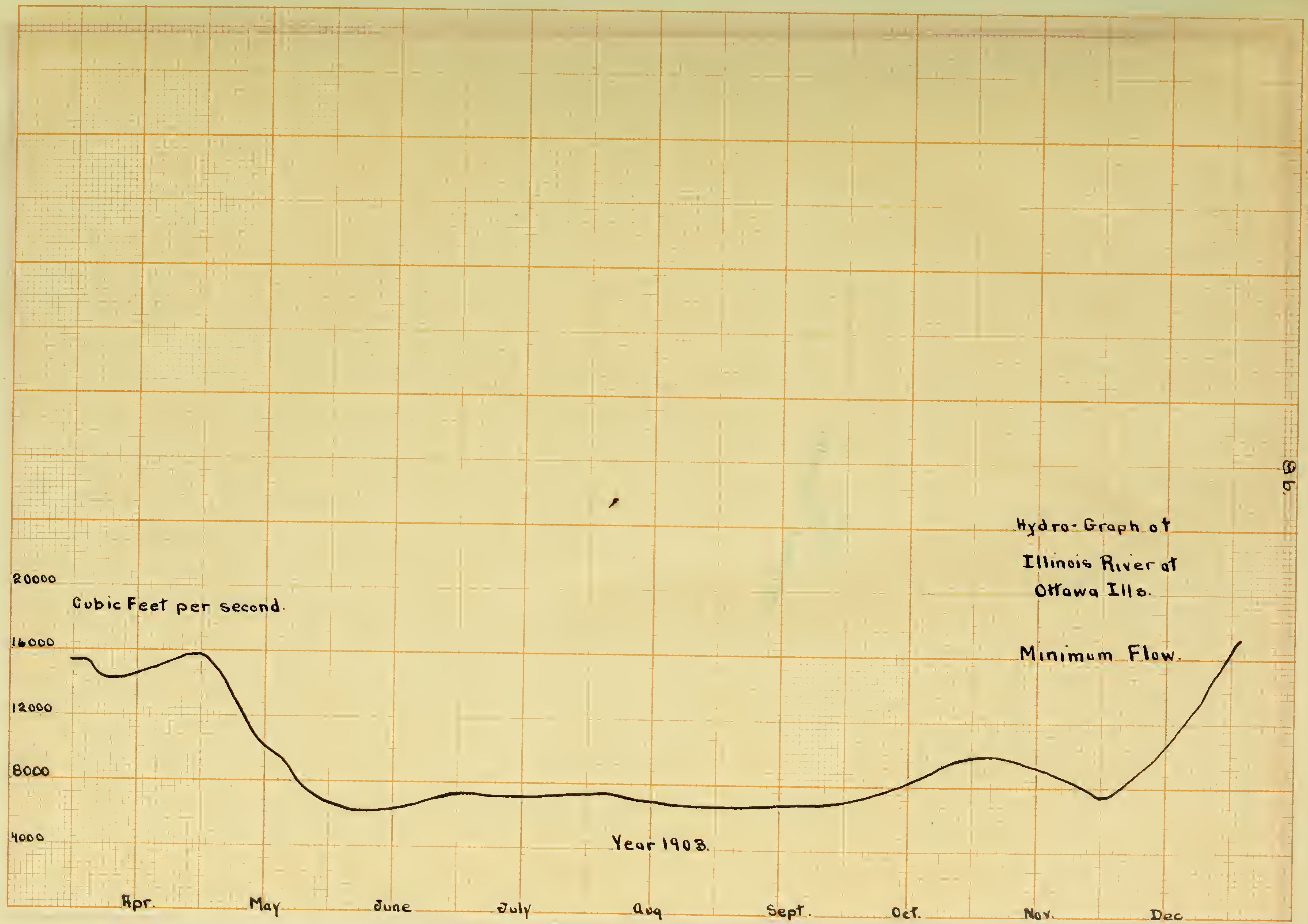

Morris
El 497
490
480
470
460
Elevation.
Ottawa
Marseilles
10
20
30
Miles.
Profile View of bed in
Illinois River from
Ottawa to Morris.
Wm. Burnett Jr.

that has been recorded in the last twenty-five years. This was a year of great floods thru out the United States and of course this gives a condition that must be taken into account in case it should again come after the plant had been installed. The annual rainfall for the year 1902 was 55.45 inches. This is about 20 inches more than falls in the average year. The next highest came in 1907 when 39.08 inches was recorded. The minimum rainfall comes in October, the lowest amount being noted in 1904, when only .26 inches fell.

In case of such a design the capacity of the reservoir is something that has to be carefully considered. The volume of water that passes the section of the river where the dam is to be located is limited between 6700 cubic feet per second and 47000 cubic feet per second. This of course is dependent on the time of the year, but the variation of the river is rather great in the spring time owing to the heavy rains and the melting snow. The maximum flow of 47000 cubic feet per second only comes the the months of March and April. The average for the rest of the year is about 11,000 cubic feet per second. The hydrograph shown on page 8a will give the relative discharges for the different times in the year. It is well to mention here that the minimum flow of 10,000 cubic feet per second is the factor that determines the size of the development. Of course before the drainage canal was in operation the minimum flow was 6700 cubic feet but the water is let in from Lake Michigan and the amount that flows past Lockport has this minimum value of 10,000 cubic feet per second. It will be possible to operate the plant for four hours under full load conditions when water is stored up with a very slight decrease in the head.

The data that is supplied for this district are a fair example of conditions that exist thru out other parts of the country that are in the central part of the United States. The conditions that exist for

8a.
60000
Cubic Feet per second.
40000
20000
12000
8000
4000
March
April
May
June
July
August
Sept
October
Nov.
Dec.
Year 1903.
Drainage area = 10,094 sq. mi.
Maximum Flow.
Hydro-Graph of
Illinois River at
Ottawa, Ills.


8b.
Hydro-Graph of
Illinois River at
Ottawa Ills.
Minimum Flow.
Cubic Feet per second.
20000
16000
12000
8000
4000
Year 1903.
Apr.
May
June
July
Aug
Sept.
Oct.
Nov.
Dec.

this development hold true for the hydro electric plants are Lockport and Keokuk. By this is meant the climatic conditions.

There is one thing that makes it possible to operate the plant rather efficiently,and that is the fact that in the summer time when the load on the system is light there is a minimum flow of water and in the winter time when the load is heavy then there is a maximum flow of water. This makes it possible to carry all the peak loads with safety and at no time in the year will there have to be an excessive storing used.

Volume of Water.

The gage height at Ottawa is measured in reference to the Hennipin datum and it varied from -119 feet to -130 feet in 1903. This is a change of 11 feet which is not very much for a river of this size. A table is shown below that gives the discharges for the river at this point for the various gage heights, from--119 to -130.

Rating table for the Illinois River.

Gage height Feet	Discharge Second Ft.	Gage Feet	Discharge Second Ft.	Gage Feet	Discharge Second Ft.
-130.0	6740	-128.3	10820	-125.2	21890
-129.9	6940	-128.2	11105	-125.0	22710
-129.8	7145	-128.1	11395	-124.8	23530
-129.7	7355	-128.0	11690	-124.6	24350
-129.6	7570	-127.8	12295	-124.4	25170
-129.5	7790	-127.6	12920	-124.2	25990
-129.4	8015	-127.4	13565	-124.0	26810
-129.3	8245	-127.2	14230	-123.5	28860
-129.2	8480	-127.0	14920	-123.0	30910
-129.1	8720	-126.8	15620	-122.5	32960
-129.0	8965	-126.6	16340	-122.0	35010
-128.9	9215	-126.4	17080	-121.5	37060
-128.8	9470	-126.2	17840	-121.0	39110
-128.7	9730	-126.0	18620	-120.5	41160
-128.6	9995	-125.8	19430	-120.0	43210
-128.5	10265	-125.6	20260	-119.5	45000
-128.4	10540	-125.4	21070	-119.0	47310

The maximum and the minimum rainfall comes in the months of March and August respectively, altho the river discharges do not come at these times because the water evaporates more readily in these months.

The next thing that has to be taken into account is the run-off per square mile. Knowing the discharge of the river the amount of run-off for each mile can be calculated. On the next page is shown the run-off in second feet per square mile of territory drained, for the sucessive months in the year of 1903. Also the depth in inches for the various months. By this it is possible to calculate the run-off for the

entire year,which was approximately 15 inches. During the year of 1903 the average run-off was .88 cubic feet per square mile . Also note that the maximum came in March and the minimum came in July.

Year of 1903.

Month	Discharge in second feet. Maximum	Minimum	Mean	Run-off. Second ft.per sq. mi.	Depth in.
March	41,775	15,620	30,111	2.98	2.33
April	46,900	15,800	25,589	2.54	2.83
May	15,270	6,840	10,700	1.06	1.22
June	16,710	7,465	10,419	1.03	1.15
July	11,990	7,570	8,657	.86	.99
August	10,540	7,570	8,922	.88	1.01
Sept.	26,400	6,740	12,106	1.20	1.34
October	12,760	9,995	11,015	1.09	1.26
Nov.	9,860	7,790	8,722	.86	1.54
Dec.	17,460	8,600	13,563	1.34	.96

The run-off is very high in this part of the country in comparsion with other sections of the United States. The one main reason being that there is a more complete net work of small streams,which take the water before it has a chance to sink into the ground. A fair estimate for the amount of run-off is about .2 to .3 of the annual rainfall. These figures hold for most parts of the United States,but they are a little low in the Illinois River basin. The annual run-off seems to be nearer .4 than .3 and this is placing it rather low. Of this discharge about one-half of the water power available can be used.

Since there are no other rivers that compare very favorably with the Illinois river in size, and of similar location, it is rather hard to make any comparisions as to the relative conditions in other streams.

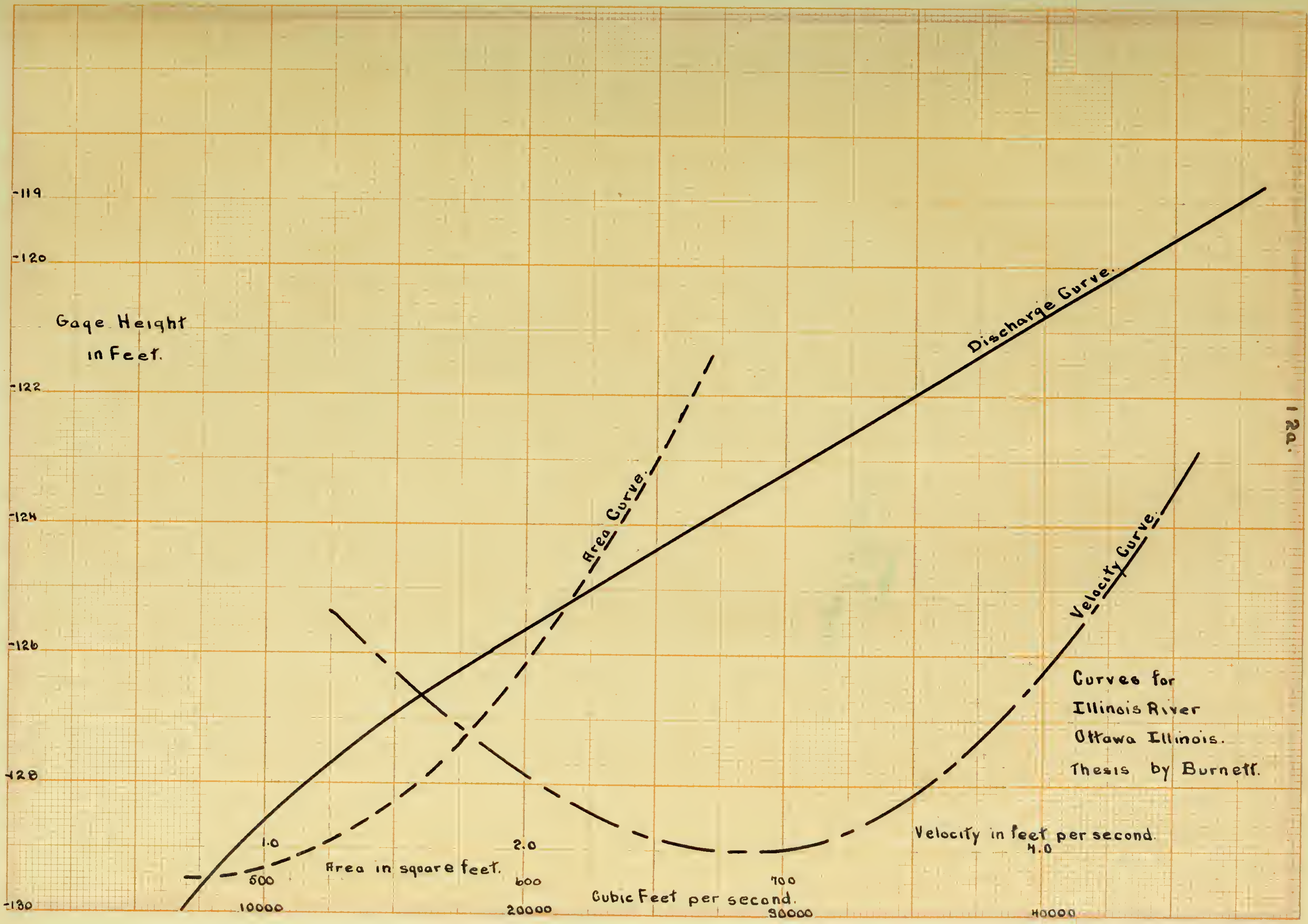
The Ohio river is probably the only one that is flowing under similar conditions. While the number of small streams that empty into the Ohio are not as great, at the same time the river has practically the same supply at its source. The variance of the flow seems to be just about the same, and the velocity of the rivers are nearly indentical for different periods of the year.

The next thing that is of importance is the methods that would be used in the office for computing the run-off of a stream. Assuming that the bed and banks of the Illinois river are permanent, then the first thing to do is determine the rating curve. This curve shows the run-off for all stages of the stream, also one that shows the gage height and the velocity in feet per second, and lastly the relation between the gage height and the cross sectional area of the stream. From these curves it is seen that the discharge, mean velocity and the sectional area is a function of the gage heights. Since the discharge is the product of the two factors area and velocity, and since a change in either will produce a corresponding change in the discharge, the curves are plotted in order to study each independently of the other.

The area curve is found by taking soundings at the section in the river, that is being studied, and these should extend as far as the high water mark.

The form of the velocity curve depends on such things as the slope of the river and the roughness of the bed. It may be either concave or convex to the axis, and in some cases is a straight line. It is also possible to have a combination of the three conditions. The slope of the river as given out by the goverment and other data that is necessary in the calculation for the discharge is as follows;

Slope	1 : 82000
Hydraulic radius	12.30



Curves for
Illinois River
Ottawa Illinois.
Thesis by Burnett.
Gage Height
in Feet.
-119
-120
-122
-124
-126
-128
-130
Discharge Curve.
Area Curve.
Velocity Curve.
Velocity in feet per second.
1.0
2.0
4.0
Area in square feet.
500
600
700
Cubic Feet per second.
10000
20000
30000
40000

Wetted perimeter	550 feet.
Coefficient of discharge	117.
Mean velocity	1.43 feet per second.
Area of section	6,764 square feet.
Discharge	9,672 cubic feet/second.

Now by means of Kutters formulae which is,

$$v = c\sqrt{RS}.$$

the discharge can be obtained without the data that has been taken by the gage readings. At all times of the year by using the above theorical formulae the discharge of the river can be found and the conditions that are to be met can be prepared for. Below is some of the data used in the design of this plant.

Data.

Date 1900	Gage	Cross Section	Mean Velocity	Discharge.
May 8	3.25	4221	2.09	8305
9	3.55	4410	2.23	9333
11	3.74	4508	2.24	9955
12	3.45	4337	2.27	9415
Apr16	4.33	4897	2.39	11745
12	4.38	4940	2.39	11803
25	4.52	4998	2.67	13343
23	4.63	5106	2.57	13133
17	4.65	5119	2.61	13172
12	4.70	5124	2.67	13678
18	5.10	5355	2.66	14205
21	5.20	5488	2.74	14992
11	5.30	5531	2.67	14614
18	5.68	5773	2.88	16599

Conditions at Ottawa in 1903.

Date	Width	Area of section.	Mean velocity.	Gage.	Discharge.
1903					
Mar.18	650	6817	4.53	122.98	30880
Apr. 5	600	4738	3.71	126.25	17570
Apr.28	610	5001	3.67	126.07	18340
May.12	545	3501	3.32	128.42	11620
Jul. 8	480	2847	2.65	129.54	7541
Aug.23	660	2924	2.62	129.57	7668
Sep.25	560	3466	3.35	128.35	11590
Oct.12	553	3609	3.75	127.38	13540
Nov.12	525	3090	2.88	129.01	8898
Dec.12	550	4424	1.54	126.42	6822
1904					
Mar.30	745	10220	4.56	118.3	46560
Apr. 2	750	10990	4.96	117.3	54470
Apr.17	626	5164	3.62	125.4	18720
Apr.26	652	6136	4.20	123.9	25920
May. 2	608	4775	3.90	125.8	18610
May.19	541	3583	2.84	128.1	10340

Mean Daily Gage Height in feet on Illinois River, Ottawa.

Day	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1			126.9	127.5	129.6	129.0	128.9	128.6	128.6	129.0
2			127.2	127.6	129.6	129.0	129.0	128.6	128.6	129.0
3		126.6	127.3	128.0	129.6	129.1	129.2	128.6	128.7	129.0
4		126.6	127.4	128.0	129.5	129.1	129.2	127.9	128.8	129.0
5		126.1	127.5	127.5	129.5	128.8	129.3	128.1	128.8	129.1
6		125.4	127.7	126.5	129.5	128.5	129.3	128.1	128.9	128.9
7		125.2	128.0	126.5	129.5	128.3	129.3	127.7	128.9	128.3
8		125.7	128.2	126.8	129.5	128.5	129.9	127.6	129.0	127.8
9		125.8	128.3	127.2	129.4	128.8	129.4	127.7	129.1	128.2
10		126.6	128.3	127.6	129.3	128.9	128.6	127.8	129.1	128.0
11	120.3	124.6	128.4	128.0	129.0	129.0	128.0	127.9	129.1	127.0
12	120.9	121.9	128.4	128.3	129.0	129.1	128.3	128.0	129.1	126.3
13	121.6	121.6	128.4	128.5	129.1	129.2	128.5	128.1	129.1	126.5
14	121.7	120.4	128.6	128.7	129.2	129.3	128.5	128.1	129.2	126.7
15	121.9	119.0	128.7	129.0	129.2	129.1	125.4	128.1	129.3	126.4
16	122.5	119.4	128.8	129.0	129.2	128.6	124.0	128.2	129.3	127.3
17	122.9	120.3	129.0	129.4	129.3	128.8	124.7	128.2	129.4	126.7
18	123.2	122.0	129.0	129.1	127.9	129.1	125.8	128.3	129.3	127.0
19	123.5	122.0	129.1	129.0	128.1	129.2	126.8	128.2	129.3	127.1
20	121.4	122.6	129.1	129.0	128.5	129.3	126.8	128.2	129.3	127.1
21	120.7	123.3	129.1	129.1	128.5	129.3	127.3	128.2	129.2	126.8
22	122.1	124.0	129.9	129.2	129.1	129.5	127.5	128.3	129.1	127.4
23	122.7	124.5	128.9	129.1	129.2	129.5	127.8	128.4	129.1	126.7
24	123.3	125.1	128.8	129.1	129.3	129.6	128.0	128.4	128.7	126.6
25	124.2	125.4	128.6	129.2	129.3	129.5	128.5	128.5	128.7	126.7
26	124.6	125.7	128.5	129.3	129.3	129.4	128.4	128.5	129.0	126.9
27	125.0	125.9	128.3	129.4	129.4	129.2	128.5	128.5	129.4	127.0
28	125.2	126.1	128.0	129.4	129.4	128.6	128.4	128.5	129.2	127.2
29	125.6	126.3	128.0	129.5	129.3	128.7	128.7	128.6	129.2	127.2
30	126.6	126.6	127.7	129.6	129.0	128.7	128.6	128.6	129.1	127.8
31	126.8				129.0	128.8		128.6		127.2

Reservoir.

The great advantage in this development is the reservoir that is to be used in storing up energy during the dry seasons of the year. This is 35 miles long and on an average .3 miles wide. The area being 10.5 square miles. When the water is raised to a height of 37 feet at Ottawa then the average depth of the river will be 25 feet. This depth will be very useful in navigation and will enable the towns within this district to have unlimited water supply.

As to the capacity of the pond it might be stated that it will contain approximately,

$$10.5 \times 5280^2 \times 25 = 7,350,000,000 \text{ cubic feet of water,}$$

or

$$7,350,000,000 \times \frac{800}{107} = 56,000,000,000 \text{ gallons.}$$

This capacity will carry the maximum load on the plant for four hours, considering that no water is fed in from the point above Morris. Assuming that all the water is to go thru the turbines and that this quanity is 6,700 cubic feet per second or 402,000 cubic feet per minute, in four hours,

$$402000 \times 60 \times 4 = 98,000,000 \text{ cubic feet would be used.}$$

The area from which this water is drawn is 10.5 square miles.

$$10.5 \times 5280^2 = 555,000,000 \text{ square feet in the reservoir.}$$

$$\frac{98,000,000}{555,000,000} = .1765 \text{ feet or the amount of head that would be}$$

lost during the full load carrying conditions for four hours. This drop is neglible with that for which the regulators will operate. From the capacity of the reservoir it is seen that a great quanity of water can be fed into the pond without raising the height to any great extent.

The governors that will be installed for this plant will correct

for a variation in head from 26 feet to 35 feet. Since it will be possible to regulate the head by the discharge over the spill-ways there will be no trouble whatever in keeping within the above limits. By adjusting the gates alone it will be possible to keep the head within the limits of 32 feet and 34 feet.

The land that is over-flowed by this reservoir is one of the biggest items of expense that will have to be dealt with. It will be possible to buy it for about $150,00 an acre. While some of this land is rather expensive still there are other portions of it that will be obtained for almost nothing. This land when thought of in comparsion with other land that lies adjacent to it is very inexpensive. If the head was to be raised 10 feet more it would over flow ground that would be worth as high as $400.00 an acre.

There are several islands that will be partly submerged with the raising of the water level. The land is very good in the production of crops but over flows very easily and the farmers at times loose their product. This land however is higher than other land that has been bought for such purposes. In the western part of the United States it is possible to get land for $5.00 an acre when used for over flow territory. Of course it is very rough and of little value for any other purpose.

Estimate of the cost of over-flow land, in the Fox River valley,

8 miles, .1 mile wide	.8 square miles	512 acres.
512 acres @ $150.00 an acre comes to		$76,700.00

Estimate of the cost of over-flow land in the Illinois River,

4 miles .05 of a mile wide	.2 square miles	128 acres.
11 miles .1 of a mile wide	1.1 square miles	704 acres.
.15 miles .75 of a mile wide	.1125 square miles	72 acres.
14 miles .1 of a mile wide	1.4 square miles	895 acres.

14 miles .15 of a mile wide	2.1 square miles	1345 acres.
6 miles .05 of a mile wide	.3 square miles	192 acres.
6 miles .25 of a mile wide	1.5 square miles	960 acres.
		4296 acres.

2497 acres	@ $200.00 an acre	$499,400.00.
72 acres	@ $250.00 an acre	18,500.00.
1599 acres	@ $100.00 an acre	159,900.00.
128 acres	@ $ 75.00 an acre	9,600.00.
Illinois River land cost		$687,400.00.
Fox River land cost		76,700.00.
Grand total for all the over flow land		$764,100.00.

This cost includes all the over-flow land and places the price per acre that was obtained from the people in the various localities.

In this cost however the moving of one mile of railroad track has not been taken into account and also moving some dwellings. The increasing of the length of several high way bridges has been left out.

Approximate estimate of moving dwellings on the over-flow land. About 15 houses on the flooded ground that are worth $800.00 each, not including the land that goes with them. These are located at Ottawa in the river bottoms, $12,000.00.

At Dayton there are three buildings that will be removed and the compensation for these is $400.00 each, 1,200.00.

At Marseilles there are two houses and one small store that will be damaged by the rise in the water level and the money allowed will be $300.00 for each house and $200.00 for the store. There are two other small buildings that are not used for anything and will not be included in this cost, but are put in the cost of the land. 800.00.

At Morris which is at the end of the reservoir $10,000.00 will have to be expended for the construction of retaining walls and the expense of moving several small buildings to higher grounds. There is also some earth work necessary on one or two of the small streams and this will amount to $1,500.00. $11,500.00.

Total cost of compensation for damage done to property $25,500.00.

Cost of moving one mile of Rock Island Track.

The cost of building one mile of track such as would be put in for the Rock Island in replacing the damage would be $40,000.00.

The cost of the right of way 12.1 acres @ $100.00 1,210.00.

Total cost for the moving of tracks $41,210.00.

Horse Power of River.

The horse power or the kilo-watts that can be developed from the river is the factor that of cuorse decides the size and the capacity of the installation. Assuming a 33 foot head then the minimum flow of the river is 6700 cubic feet per second, the horse power that can be developed from this is,

$Q =$ quanity of water in cubic feet per minute.

$H =$ height of the water fall.

$W =$ weight of a cubic foot of water.

Then the formulae for the horse-power is,

$$\text{Horse-power} = \frac{Q \times H \times W}{33000}.$$

The horse that can be developed during the minmum flow of the river is given,

$$\text{H.P.} = \frac{6700 \times 33 \times 62.5 \times 60}{33000} = 25{,}510 \text{ H.P.}$$

25,510 horse-power is equal to 18,700 kilo-watts.

Since the turbines have 85% efficiency and the generators 95% efficiency then the loss in power that comes from the water is 19.3%. Ther out of the 18,700 kilo-watts only 15,080 kilo-watts would be available. This value is for the driest time of the year when the peak lead onthe station is 21,000 K.W. The average day load is 10,000 K.W. and it is seen that it will be no trouble to store up enough water to supply the plant for the peak load the following day. These conditions are the ones that would have to be met if the Lockport plant had not been installed and were taken up just to show the possibilty of the larger development when this condition is present. Since this installation at Lockport the minimum flow of the river has been 10,000 cubic feet per second. This is let thru from Lake

Michigan. The horse power of the river under the present conditions and the ones for which the plant was designed is,

$$H.P. = \frac{10000 \times 33 \times 62.5 \times 60}{33000} = 37,500 \text{ H.P.}$$

37,500 horse-power is equal to 28,000 kilo-watts.

Assuming the efficiency of the machinery to be 75 per cent then the power that could be obtained is,

$$28000 \times .75 = 21,000 \text{ K.W.}$$

This 21000 K.W. then is the minimum power that will ever be obtained from the river. If at some time the plant will have to be enlarged then the reservoir will come into use,but at the present time this will not have to be used. Considering the dry time of the year,and the river developing 21,000 K.W. for the day,then it is possible to supply an average load of 19,000 K.W. for the 18 hours and then a peak load of 50,000 K.W.

21000 x 24 = 505,000 K.W.H. or the number of kilo-watt-hour per day.

If the average day load is 19000 K.W. and this lasts for 18 hours then,

19000 x 18 = 342,000 K.W.H. used during the 18 hours of operation.

The amount saved during this time then is,

505,000 -- 342,000 = 163,000 K.W.H.

Then if the peak load lasts for six hours the capacity of this load can be

$\frac{163000}{6}$ = 27,200 K.W. or the maximum peak load that can be taken off when the full capacity of the plant is installed. Since only 23,000 K.W. is to be used at the present time then there will be times of the year in the dry season when a certain amount of water will go to waste over the spill-ways,this value for this set of conditions is,

27,200 -- 23,000 = 4200 K.W. of energy going to waste over the spillways.

4200 K.W. converted into the discharge of the river in cubic feet per

second is,

4200 K.W. is equal to 5630 H.P. then,

$$Q = \frac{5630 \times 33000}{33 \times 62.5 \times 60} = 1500 \text{ cubic feet per second.}$$

This is the water that will be wasted during this time of the year until the completed installation is ir operation.

During the heavy flow periods of the year which come in the spring, the power that can be developed from the river is shown in the following calculations.

Maximum flow of river 47000 cubic feet per second, then,

$$H.P. = \frac{47000 \times 33 \times 62.5 \times 60}{33,000} = 176,000 \text{ H.P.}$$

176,000 H.P. is equal to 131,000 K.W. Again assuming that the machinery is 75% efficient then the power obtained from the river is, 176,000 x .75 = 132,000 H.P. or 98,500 K.W. that could be supplied if this flow would last. These conditions of course only last for a few days at a time and it is at that period that the high water exists and in a great many cases it will be necessary to open up all the gates to let the discharge by. The dam will be designed however so that only about three fourths of the gates need be opened at flood times. This is because the dam is very wide and it will be calculated for the most extreme cases.

The velocity of the water on the tail-race is to be 5 feet per second which is a rather high current in a river of this size. In all probablities it will have to be dredged out and this will cost a great deal of money. The river at present is very sluggish at this point and the velocity is not great enough to carry off the water if this was not done.

The Dam.

In considering this dam it will be possible to give results that have been taken from good authorities, and the following explanation will be needed.

A road way is to be constructed over the dam when it is finished and the top part of the dam will have to be designed for this. This is to be used for the operation of electric cars from one side of the river to the other. It will be possible to lay a road bed on the top if the width is about seven feet, and therefore this dimension will be used. The rest of the dimensions for the construction comes thru the use of empirical formulae that was obtained from some well known books on the design of dams.

The foundation is one of the most essential things that comes in to the first general survey of the dam. At the point which the development will be located the river has bluffs on each side of it rising to a height of 75 to 80 feet. This will give the shortest dam that it would be possible to construct anywhere in the river. The bed of the river is made up of gravel and sandstone which is a typical foundation for the town of Ottawa. Under this bed of sandstone there is a bed of hardpan or bed rock. However it will not be necessary to go as deep as the bed rock because the sandstone will give a good foundation for the dam.

The next thing that is of importance is the head that the dam will have to hold. Since the average depth of the water in the river is about 8 feet, then it is seen at once that to give an elevation of the head above the tail water of 33 feet the dam will have to be at least 41 feet high. Now there must be added in the foundation height which will be about 5 feet. Also the dam should rise about 7 or 8 feet above the surface of the water. Then in all the dam will be nearly 50 feet high, from the bed to

the roadway. The calculations for these things will be taken up later.

The center of gravity, the over turning moment and the sliding force must be determined. In these calculations the excessive stresees such as flood conditions and heavy storms, will have to be allowed for.

The gravel is to be obtained directly from the bed of the river. It will not be necessary to go over two miles to get the required crushed rock that is needed. The cement can be obtained from one of the Portland cement works which is located between Ottawa and LaSalle. This gives ideal conditions for getting materials when needed also having it on the job at the right times. The Tainter gates that are to be used will be bought of some firm that is close at hand so that freight charges will not be excessive and also the gates when shipped can be handled in one piece and this will save the time of assembling them on the job. The accessories such as the lifting devices for the gates and the hardware can very likely be purchased close by. The cost of the materials was obtained directly from the company.

Calculations for the Dam.

Data shows that the best results in former construction for the dimensions of the crest should be obtained from the following formulae,

Width of the crest in feet $(4.0 + 0.7 H) = 7.15$ feet,

where H 33 feet or the head of water that is to be used.

The height of the dam above the water level is determined from this equation, of Van Schon,

Height of the dam above the water $(1.8 + .5 H) = 4.05$ feet.

The up stream side of the dam is vertical and the down stream side is in the form of a parabola.

Usually the base of the dam is taken as .8 of the head of water which it is holding back, the width of the top is taken as .2 of the head. The over turning moment here is rather large and the base firgures out to be 30 feet.

Head of water	33 feet.
Fonndation height	5 feet.
Average depth of river	8 feet.
Height of roadway bed	4 feet.
Space between roadway and water	3 feet.
Total height of the dam	53 feet.

The above data was obtained by the use of Coventry's empirical formulae and is subject to alterations regarding exsisting conditions.

Constants that were used in calculations.

Specific gravity of concrete 2.25 to 2.5

Weight of concrete 140 to 150 pounds per cubic foot.

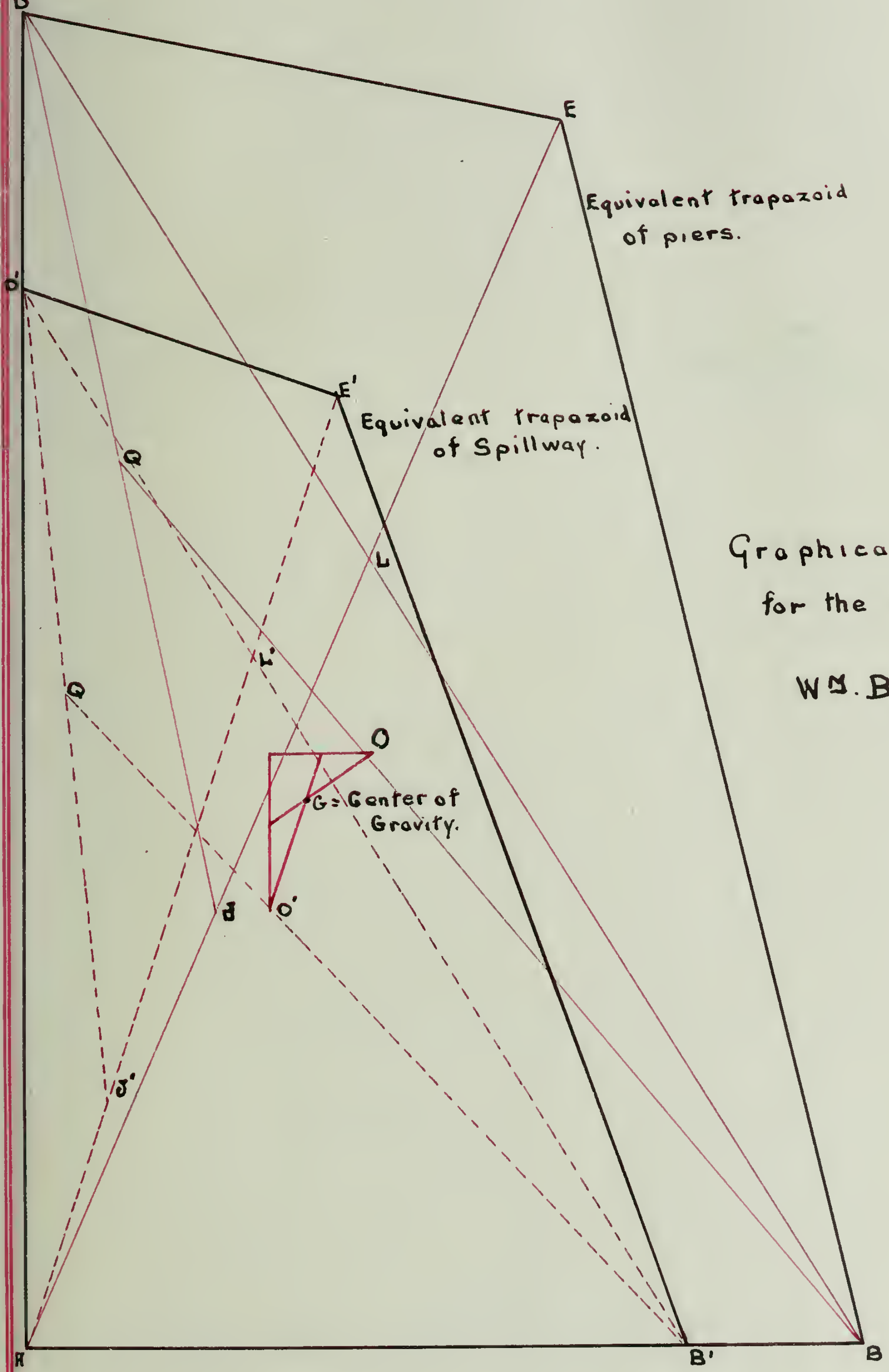
Coefficient of friction between masonary and dry clay .510.

Coefficient of friction between masonary and wet clay .385.

Calculations for the Center of Gravity.

It will be necessary to divide the dam up into two sections. The spillway is to be considered as one section and the piers of the spillways the other section. The center of gravity is to be found grahpically.

Get each section into an equivalent trapazoid. Then the centers of these two sections are found and the resultant of these two centers will give the center of gravity of the dam. By equivalent trapazoid is meant, one that will most nearly fit the outside dimensions of the section. Considering the spillway first; Given the figure ADEB. Draw lines connecting DB and EA. Call the intersection of these two lines L. Now lay off on the line AE the distance LE from A. Call this lenght AJ. Draw a



Graphical Solution
for the Center of Gravity.

Wm. Burnett Jr.

line from J to D, and bisect this line. From the bisection Q draw the line to B. Then one third of this distance from Q to B will give the center of gravity of that section. Lines are drawn in the horizontal and the vertical planes from the two points that were determined by the foregoing methods. Draw medians of the triangle and the point where they intersect gives the true center of the dam. This only gives approximately results but they are close enough to answer the purpose.

Results.

Considering the vertical side of the dam as the Y axis and the horizontal side as the X axis, then the center of gravity can be refered to as,

$$X = 10.0 \text{ feet.}$$

$$Y = 19.5 \text{ feet.}$$

This means that the center is located 10.0 feet from the right of the vertical line and that the height above the base is 19.5 feet. From this the pressure of the water against the dam can be calculated and the rest of the factors which determine the size of the section can be obtained. The way in which the over turning moment is obtained is to take moments about G as a center and this will give values in footpounds. Then the base must be of such a dimension that it will resist this over turning moment, and keep the dam in the upright position.

The pressure against the up stream face is given by the following equation,

$$P = .433 \times H \times A$$ where A is the area of the surface and H is the head of water above the geometrical center of the body.

$$P = .433 \times 17.5 \times 1 = 7.6 \text{ lbs. per sq. in.}$$

The pressure on one square foot then is 1095 pounds. And on the entire dam,

$$P = 7.6 \times 144 \times 1060 \times 33 = 38,300,000 \text{ pounds.}$$

The sliding force is obtained from this empirical formula,

$S_f = 31.25\ h^2 = 31.25 \times 33^2 = 33800$ lbs, per sq. ft.

This force is the one that resists the moving of the dam from its foundation. The pressure that tends to slide the dam along is that of the water and this force is, 38,390,000 pounds.

The area of the dam at the base is,

$$A = 35 \times 1060 = 37,000 \text{ square feet.}$$

then,

$$37.000 \times 33,800 = 1,250,000,000 \text{ pounds,}$$

this is force needed to move the dam. The dam is then designed with a safety of 20 with reference to this calculations.

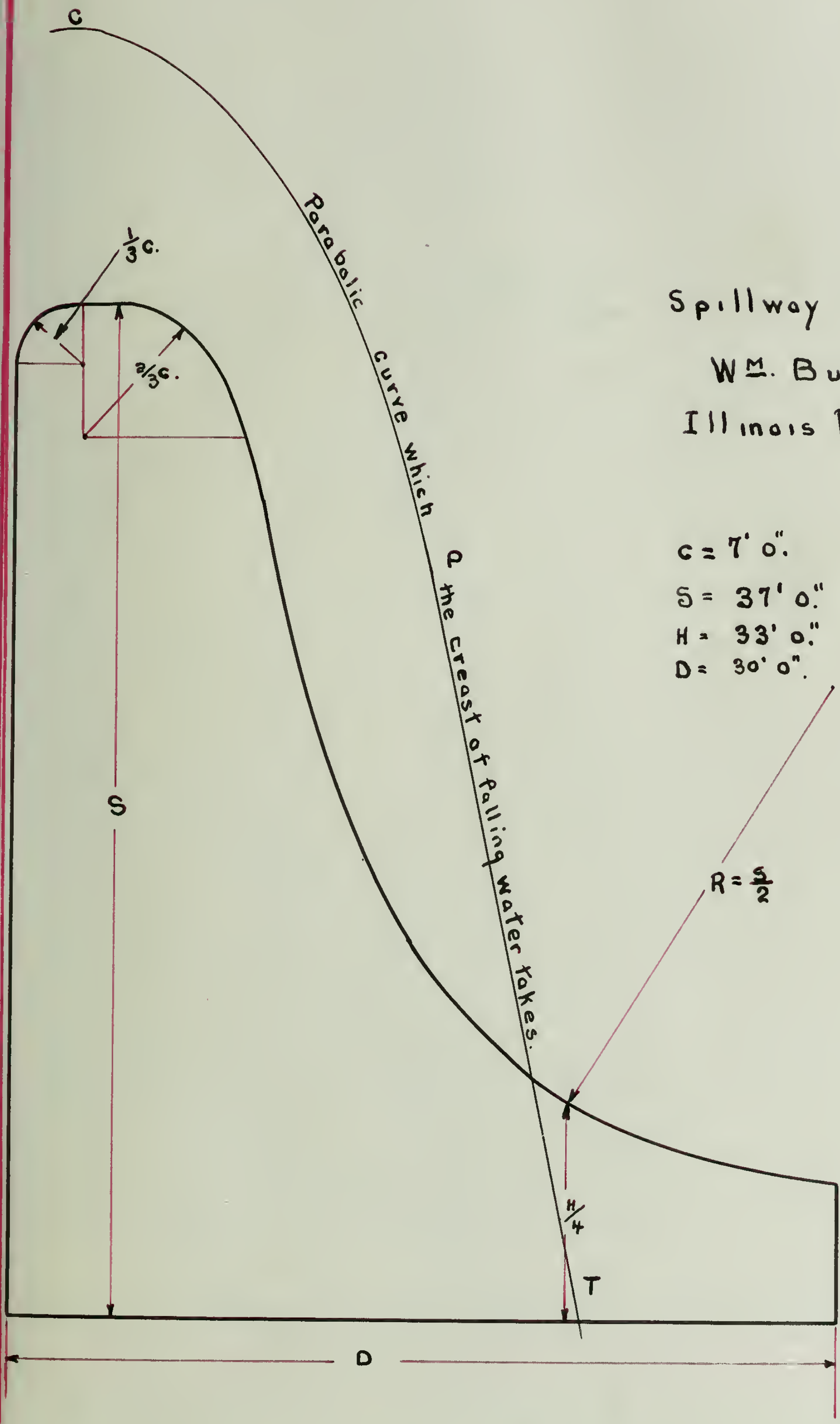
The over turing moment of the dam is given by the formula,

$M = .33 \times H \times h$ where h is the lever arm of the force acting.

$$M = 10.42 \times 33^2 = 360,000 \text{ lb. ft,}$$

The factor of safety against over turing then is also large. The dimensions given here are standard sizes for all the dams that have been constructed of this size. A large safety factor is used so that the construction will stand any abnormal pressures. These pressures can be caused by heavy waves and frost. The frost is the biggest force and this will be allowed for by expansion joints.

When the river stands at 33 feet the gate if wide open will allow water 10 feet deep to flow over the spillway. The following dimensions give the shape of the spillway such that the greatest amount of water can be discharged over the spillway in the shortest time. The curve which any falling body takes when forced out in a horizontal plane and



Spillway Design.

Wm. Burnett, Jr.
Illinois River Co.,

C = 7' 0".
S = 37' 0."
H = 33' 0."
D = 30' 0".

is acted upon by the force of gravity, forms a parabola. The equation of the curve is,

$y^2 = 4\ ax$, or it is represented by the line CPT on plate #26a

The shape of the spillway will follow directly along this line since this gives just the friction of the concrete against water, and does not allow any air pockets to get between the dam and the water. This is very important for in some former dam construction there was a great deal of trouble due to the washing away of the foundation of the dam and causing a complete wreck. This washing away is due to the fact that if the down stream side is vertical then the water in falling over the spillway forms a suction chamber between it and the dam, and the air pressure forces the water back against the base, causing wear on this part. Plate 26a will show the results taken from the practical design of the ogee dam which is the standard kind the goverment installs.

The vertical up stream side is rounded off at the top with a quarter round. This radius is taken as one third of the dimension C. The curve CPT is a true parabola and starting at K the equation is $y^2 = 4\ ax$, holds until the point C is reached. This point is taken at the distance $H/4$. From C the water is is then deflected into the horizontal plane and to do this the face of the spillway is rounded off using the radius R $S/2$. This gives the face that will discharge the greatest amount of water in the least time. The friction factor here is just the same as if the water was flowing in a channel with this concrete for sides and bottom. The discharge from the spillways of the ogee type dam is as follows,

$Q = 3.33\ b\ H^{\frac{3}{2}}$ where b is the width of the weir in feet and H is the effective head in feet. Then the discharge for a ten foot head over this dam is,

$Q = 3.33 \times 20 \times 10^{\frac{3}{2}} = 2080$ cubic feet per second.

When the plant is using 10,000 cubic feet per second and the river is at one of its highest stages then 37,000 cubic feet per second will be discharged over the spillways which will require 23 Tainter gates to be open. During abnormal floods it will be necessary to open all the forty gates and this will discharge the water that has been flowing during these conditions. This abnormal condition comes about every ten years according to the goverment reports.

Tabulated results of the calculations on the dam.

Total height of dam from base to roadway		52 feet.
Head of water it will hold back		33 feet.
Area of the spillway		200 sq.ft.
Width of the top or roadway		7 feet.
Width of the base		30 feet.
Height of the road way above water level		6 feet.
Pressure on the up stream side		38,300,000 lbs.
Force that tends to resist sliding		1,250,000,000 pounds.
Over turning moment of the dam		360,000 lb.ft.
Radius of Tainter gates		10 feet.
Length of dam		1060 feet.
Width of piers between spillways		6 feet.
Height of the foundation		5 feet.
Height from base of dam to crest of spillway		37 feet.
Excavation for the foundation	58% mud 9% gravel 33% sandstone	5900 cu. yd.
Concrete in the dam		33,850 cu. yd.
Tainter gates		40 .
Total weight of dam complete with gates		66,044 tons.

Cost of Dam and its acessories.

Excavation for the foundation	5900 cu. yd. @ $1.50	8850
Solid concrete for the base	5890 cu. yd. @ $6.00	35000
40 piers each of 226 cu. yd.	10600 cu. yd. @ $6.00	64000
Spillway concrete	16120 cu. yd. @ $6.00	96700
Bridge way	1100 cu. yd. @ $6.00	6600
Cost of concrete installed		$211,350.00
Fofty Tainter Gates	@ $200.00 each	8,000.00
Installation of the above including acessories		10,000.00
Total cost of gates		$18,000.00
Railway bed over the roadway, including the track laying 1060 feet costs		$10,000.00

Cost of the concrete construction	$211,350.00
Gates	18,000.00
Railroad	10,000.00
Cost of dam complete	$239,350.00

Cost of the timber.

The timber that will be used in the forms for the dam construction will be a dead loss unless it can be sold after it has been used. The cost of this timber is roughly estimated in this way. Enough lumber will be used to place forms for 200 feet of the dam. This will necessitate about 2,000,000 board feet of lumber, costing $30.00 per M, then

2000 M x $30.00 = $60,000.00.

Cost of the coffer dam and ice fender.

The coffer dam will be a dead loss also. This will cost about $4.25 per foot for a 33 foot head, the data being obtained from Gillette's

Cost Data book. Then 1060 x $4.25 = $45,000.00.

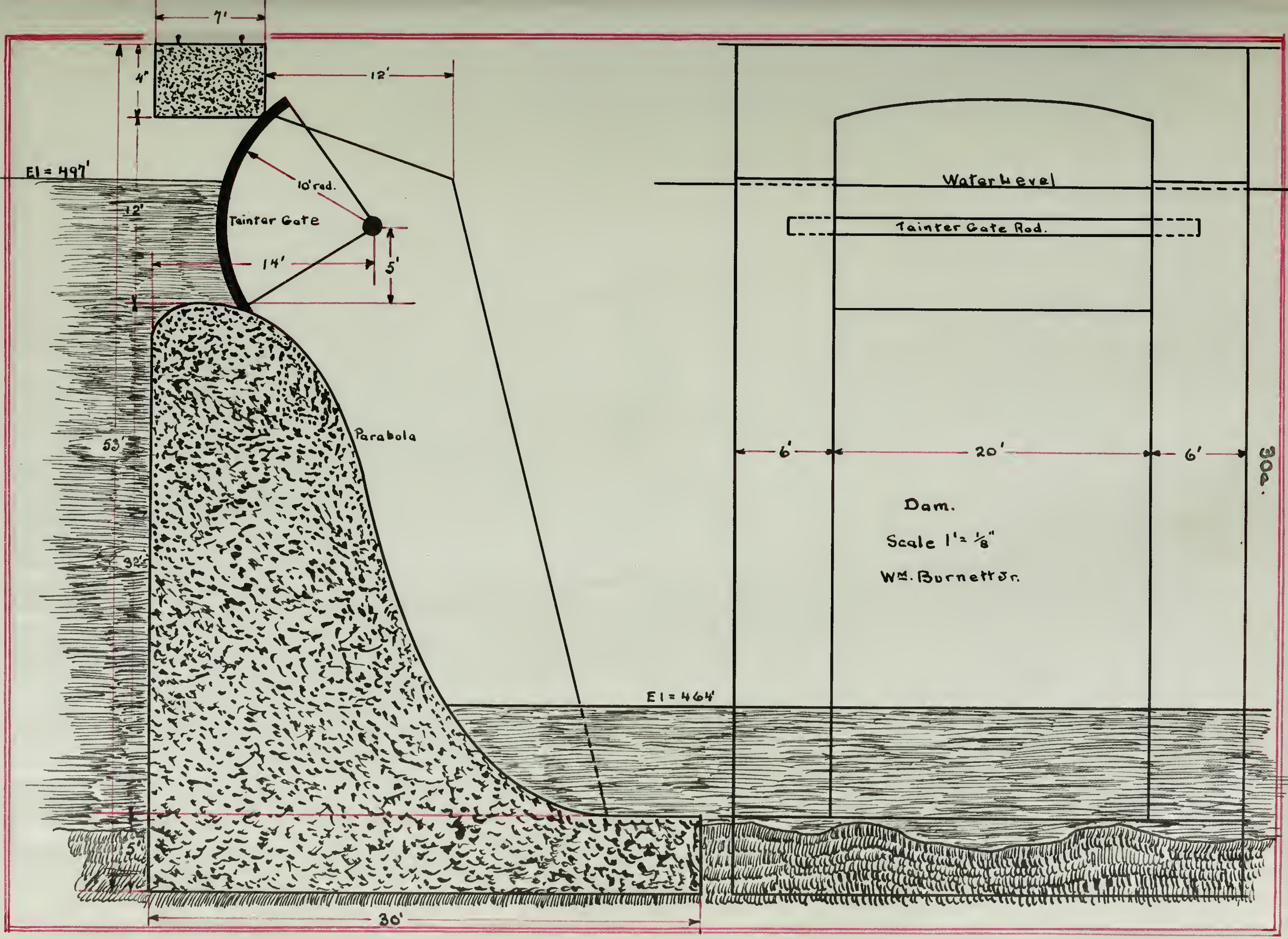
The ice fender will be the protection to the dam when the ice begins to break up in the spring. This will also stop logs and other matter that floats down the river. For driving the piling for this fender it will cost according to the foregoing reference $10,000.00.

The government requires that the navigation up this river shall not be interfered with therefore it will be necessary to build a lock to lift the boats. This lock will be 200.ft long and large enough to pass the largest boat and is to be installed at a cost of $95,000.00.

Tail-race.

The cost of dredging the tail-race so that the water will have sufficient velocity is a big item of expense. The river will have to be cleaned of silt and dirt that is about three feet deep. In order that during flood conditions the water will not back up this dredging will have to cover a mile of the bed. The cost of removing the dirt at 50¢ per cubic yard will be,

587,000 cubic yards at 50¢ = $263,500.00

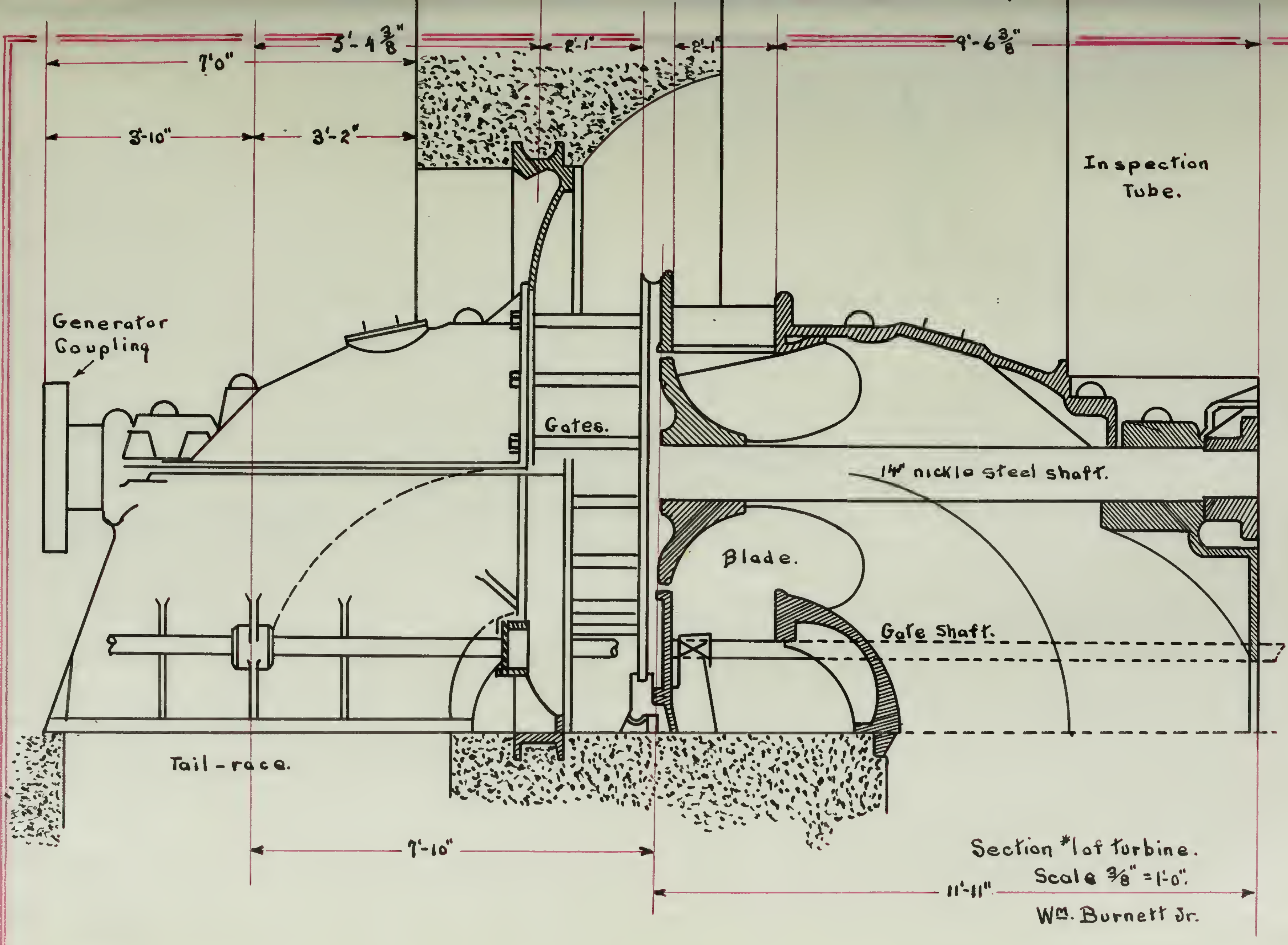

30a.
7'
4"
12'
El = 497'
10' rad.
Tainter Gate
14'
5'
12'
53'
32'
5'
Parabola
30'
El = 464'
Water Level
Tainter Gate Rod.
6'
20'
6'
Dam.
Scale 1' = 1/8"
Wm. Burnett Jr.

The Turbines.

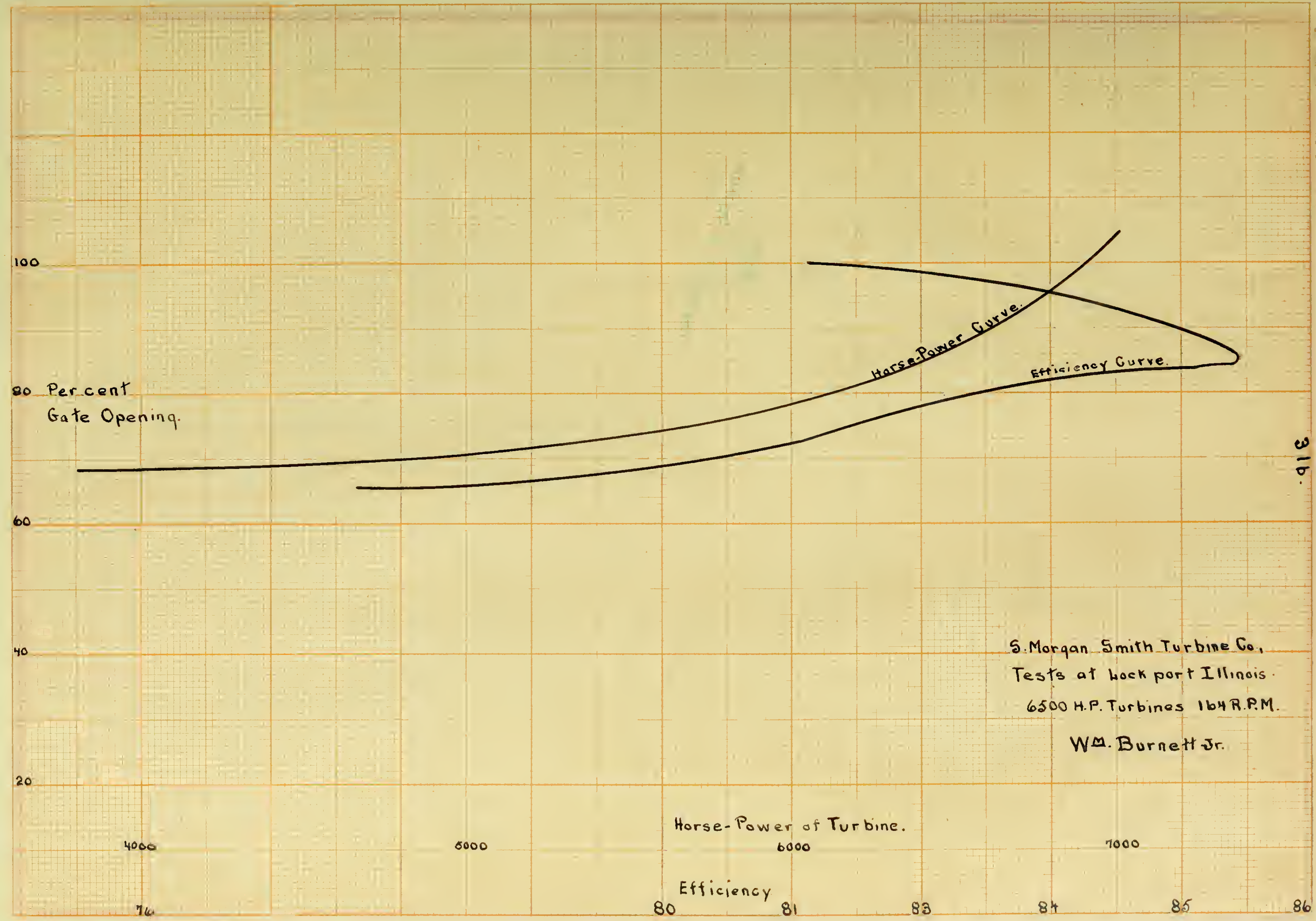
The six turbine units are to be 6500 horse-power each driving one main generator unit. They are the horizontal type running at 164 r.p.m. and having 81.2 % efficiency, at full gate. Each turbine unit is made up of six small units operating on the same shaft and this is controlled by a Lombard governor having a rating of 60,000 foot pounds. The governor will keep the speed constant with a variance of head from 29 to 36 feet.

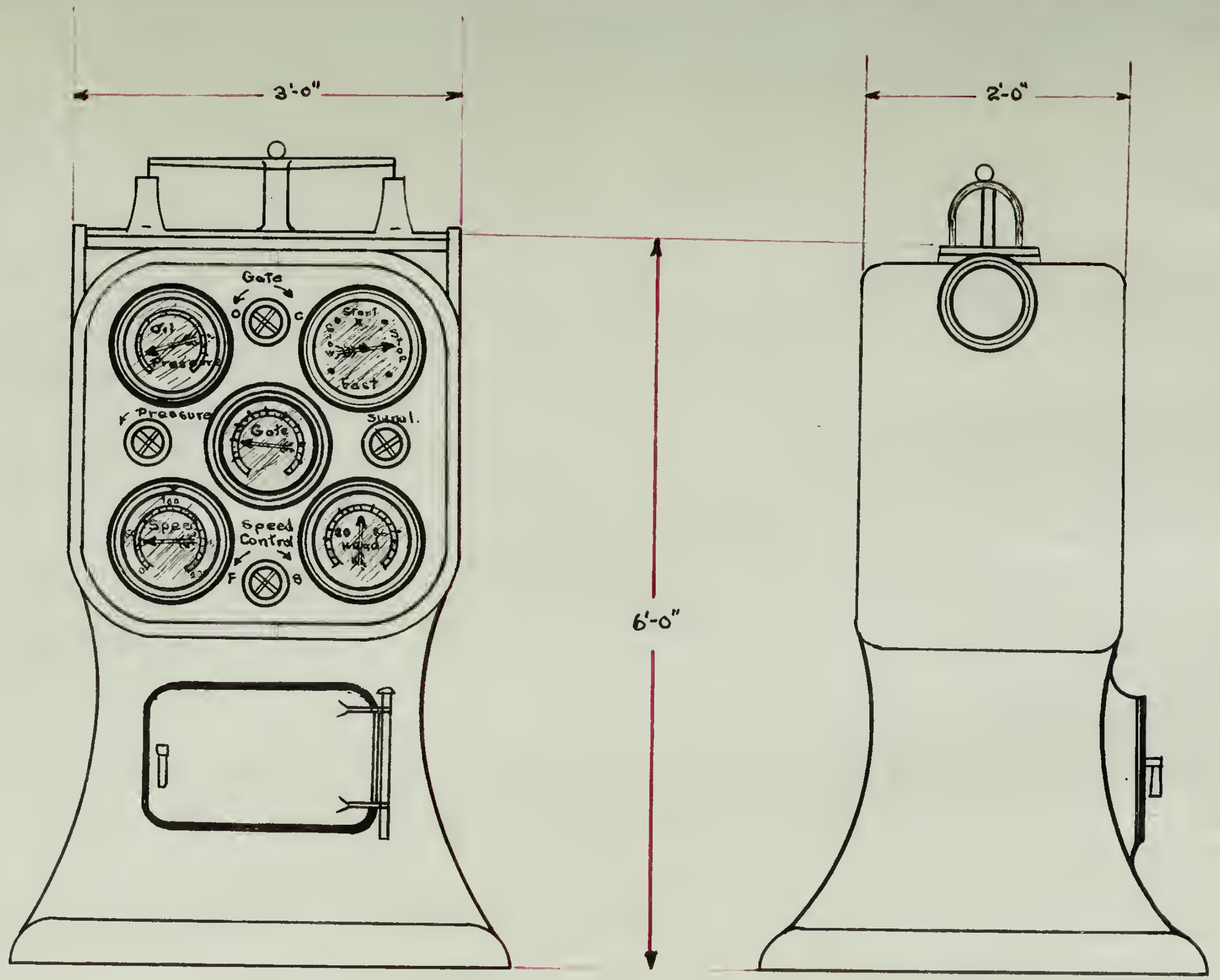
A drawing of two of the small units that make up the main unit can be found on the next page. The total length of the six turbines when they are coupled in series is about 60 feet. The shaft is 14 inches in diameter and made from the best nickel steel. The inspection tubes that are shown on the plate give access to the bearings which are three in number. These bearings are fed by a high pressure oiling system, which keeps new oil always around the shaft. The Lombard governor has a shaft that runs the full length of the turbines. This controls the gates so that the speed can be held constant.

The foundation is to be of concrete about 25 feet deep. This has to be rigid as there are heavy torsional stresses set up in the shaft and if there is excessive vibration there might be trouble due to the bearings heating. On the next page is shown the curves that were obtained from tests on the same kind of turbines at Lockport Illinois. This shows the per cent gate opening plotted against the efficiency at this point. There is also a curve that shows the horse-power plotted against the various gate openings. These two tests were made after the units were ready for operation and show very good operating characteristics. The two turbines that will drive the exciter units are 700 horse-power each. They run at 249 r.p.m. and at full gate give an efficiency of 8[illegible].5%. This turbine unit is made up of two units rated at 350 H.P. each and mounted on the



Section #1 of turbine.
Scale 3/8" = 1'-0".
Wm. Burnett Jr.


100
80 Per cent
Gate Opening.
60
40
20
Horse-Power Curve.
Efficiency Curve.
S. Morgan Smith Turbine Co.,
Tests at Lockport Illinois.
6500 H.P. Turbines 164 R.P.M.
Wm. Burnett Jr.
Horse-Power of Turbine.
4000
5000
6000
7000
Efficiency
76
80
81
83
84
85
86



Lombard Governor.
60000 Foot Pound Capacity
For use in control of
one Main Unit.
Wm. Burnett Jr.

same shaft.

Cost of the Turbines.

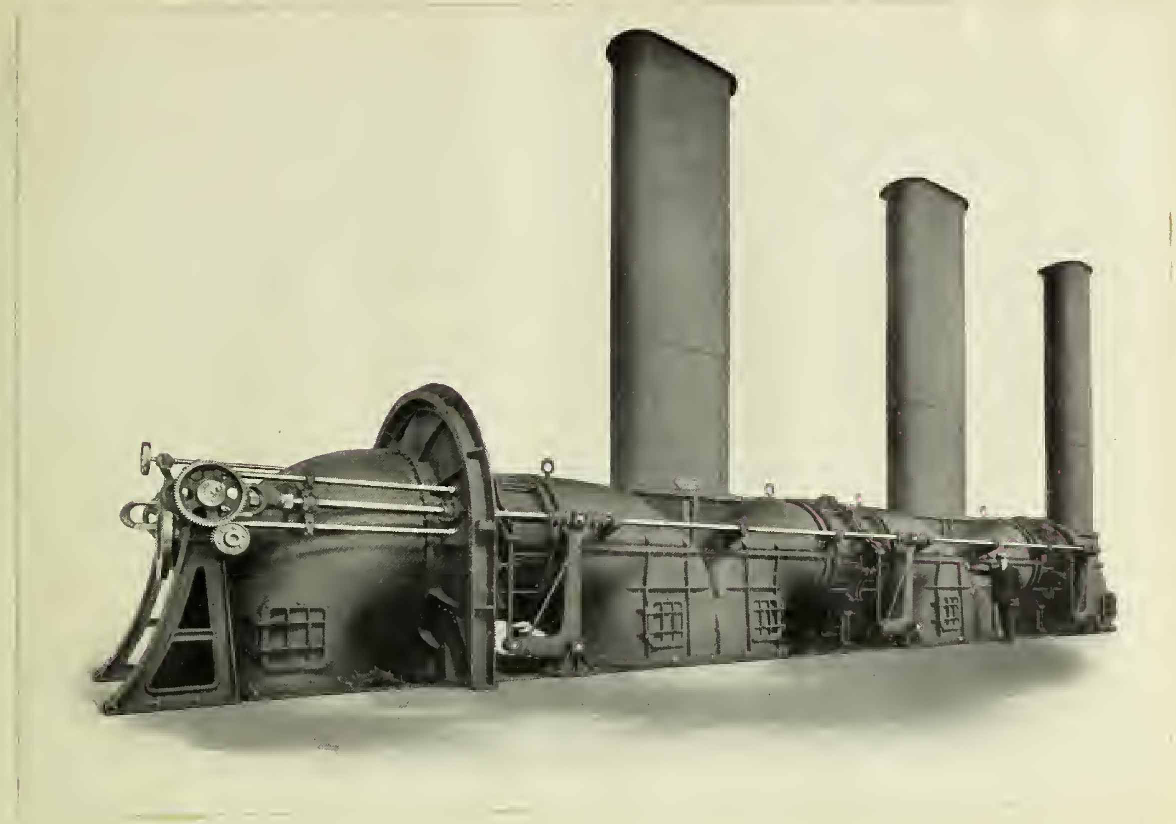
Each unit will cost $29,000, including the setting and the labor, the cost comes up to $35,000. This was the price that the Lockport units cost.

Cost of six units, complete	$210,000.00.
Cost of the two turbine units	7,000.00.
Total cost of turbines	$217,000.00.
Cost of the six Lombard governors for the large units,	
Six at $3,000 each	18,000.00.

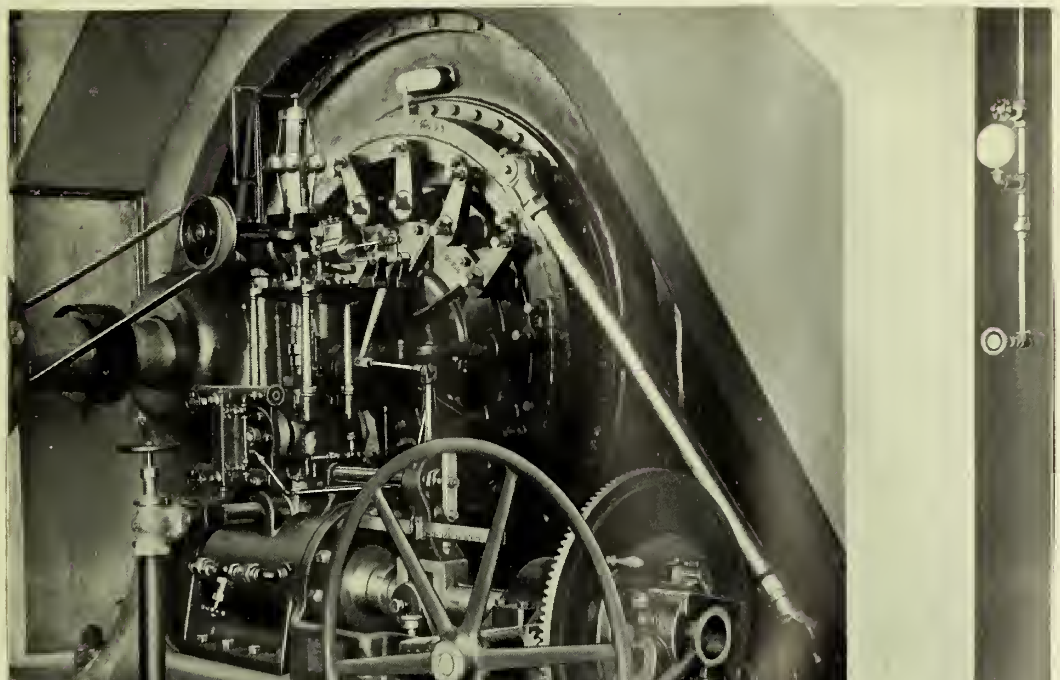
The above includes the cost of installation for all the machinery and accessories.

Each turbine unit that drives the main generator weighs 90 tons. The weight of the exciter turbines will be about 10 tons each. The cost of machinery and installation was figured from data obtained from the S. Morgan Smith Co. which allows from $10.00 to $15.00 a ton for the work.

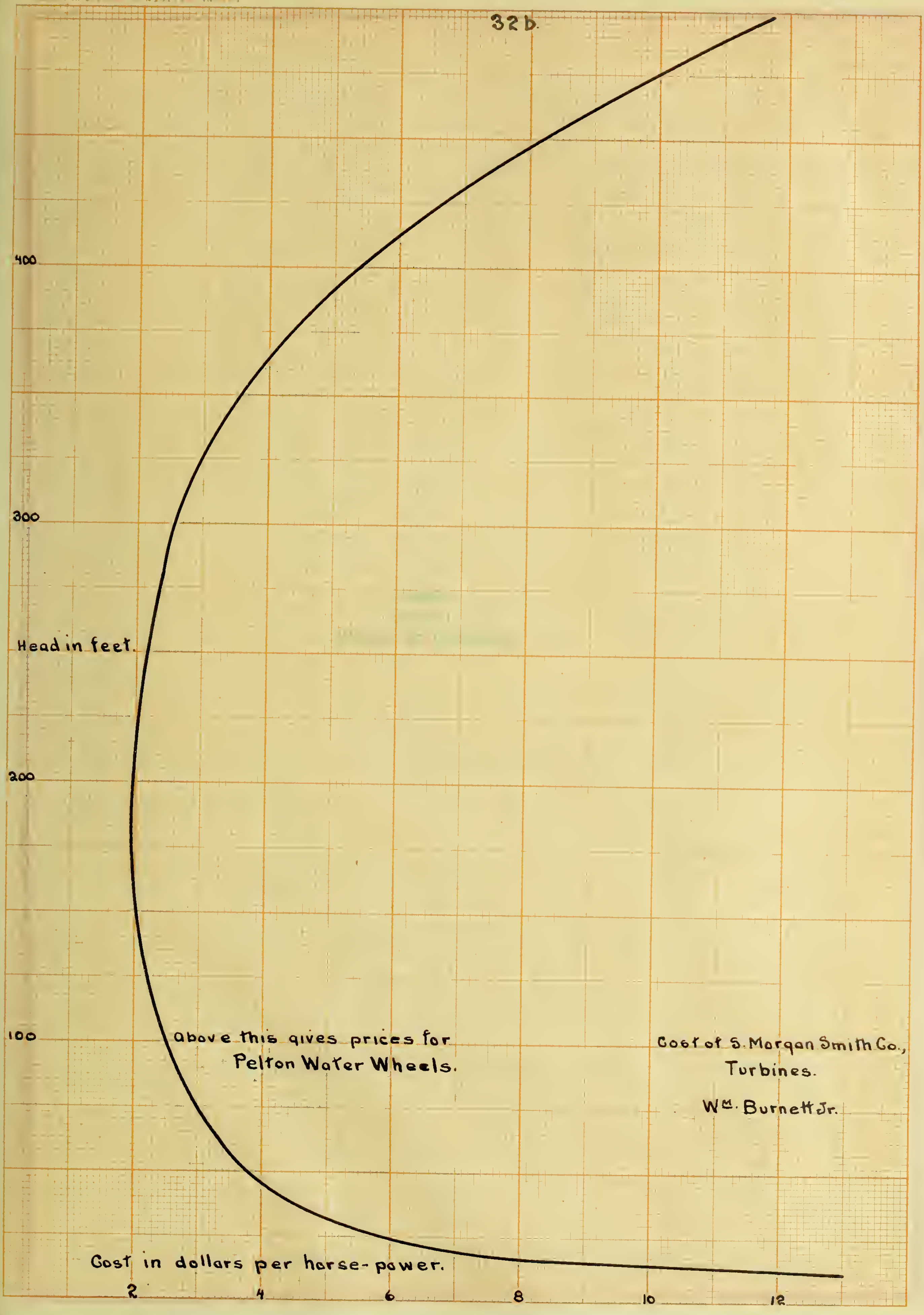
One of the main objects in the decision of the size of units and the type was to obtain something that was of standard size thereby saving money.



Main Turbine Unit.



Governor.


400
300
Head in feet.
200
100
above this gives prices for
Pelton Water Wheels.
Cost of S. Morgan Smith Co.,
Turbines.
Wm. Burnett Jr.
Cost in dollars per horse-power.
2
4
6
8
10
12

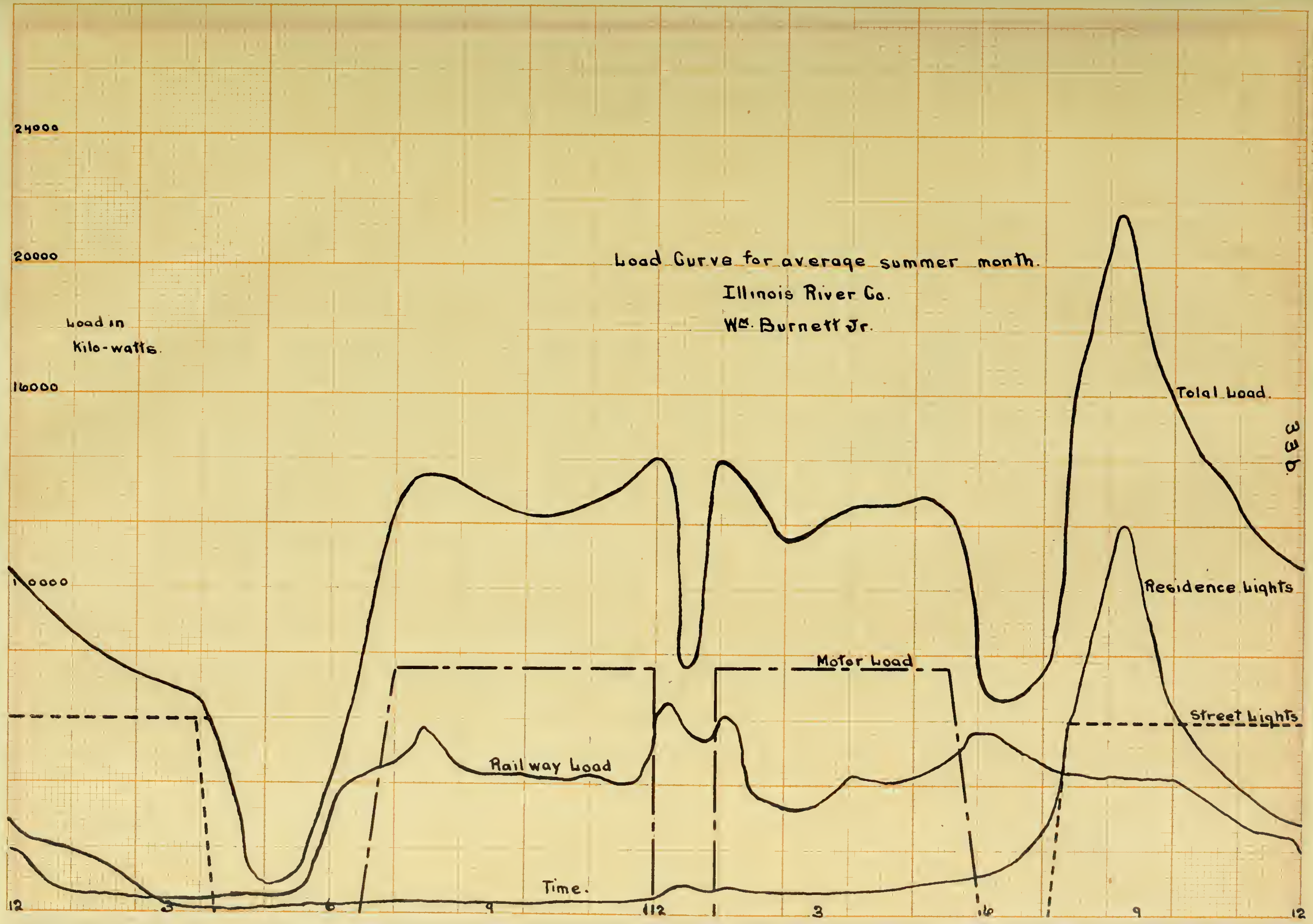
Towns that are to be supplied with power.

The present towns are supplied with power by the McKinley system and the idea of this installation is to do away with the steam plants, for power can be made much cheaper in this way. The only thing that is holding back the McKinley people from putting in this installation is that there are several goverment matters to be settled before this can come about.

Towns.	Population.	Lighting Load.	Railway Load.	Street Lights.	Motor Load.
Ottawa	10,000	500	300	200	Motor load for list
Marseilles	3,000	150		50	
Bloomington	40,000	1500	500	750	
Peoria	80,000	3500	1000	1500	
Pekin	5,000	250		100	
Decatur	50,000	2500	750	1000	
Clinton	5,000	250		50	
Morris	2,000	100		50	
Springfield	60,000	3000	900	1200	
Champaign	20,000	1500	300	300	
Danville	40,000	2500	750	750	
Total	315,000	15750	4400	5950	7500

Motor load was taken as an average load for two or three repersentive towns. The total connected on the plant will be 33,600 K.W. Good authorities give out the fact that 50 watts per capita is the usual lighting load for any town and it is well to notice that these figures come out about that way. The load curves for the conditions in December and June are given on page #33a.


39a.
Winter Load Curve.
Illinois River Co.,
Wm. Burnett Jr.
Load in
Kilo-watts.
26000
24000
22000
16000
10000
Total Load.
Residence Load.
Motor Load.
Street Lights.
Railway Load.
Time.
12
3
6
9
12
3
6
9
12


33 b.
Load Curve for average summer month.
Illinois River Co.
Wm. Burnett Jr.
Load in
Kilo-watts.
24000
20000
16000
10000
Total Load.
Residence Lights
Street Lights
Motor Load
Railway Load
Time.
12
3
6
9
12
3
6
9
12

Electrical.

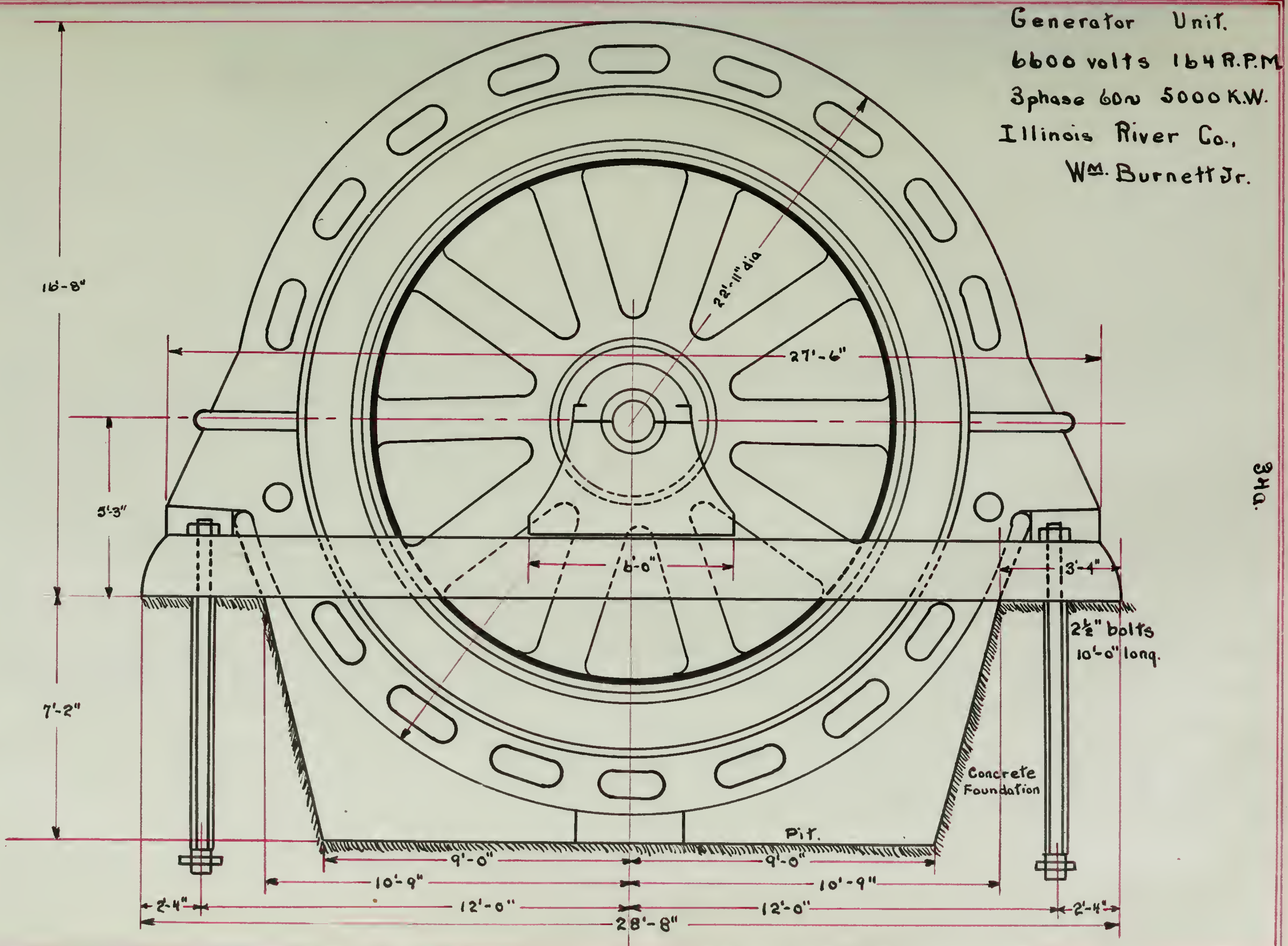
The load curves show that the load varies for different times in the year. In the month of December there is a very much greater demand than there is in the month of June. The peak load in December is about 27,000 kilo-watts and this will be the quanity that is to decide the capacity of the plant. In June the peak load calls for 23,000 kilo-watts. This will then necessitate that some of the units remain idle during the summer months. However this is more economical then it would be to install an auxiliary plant for the winter overload.

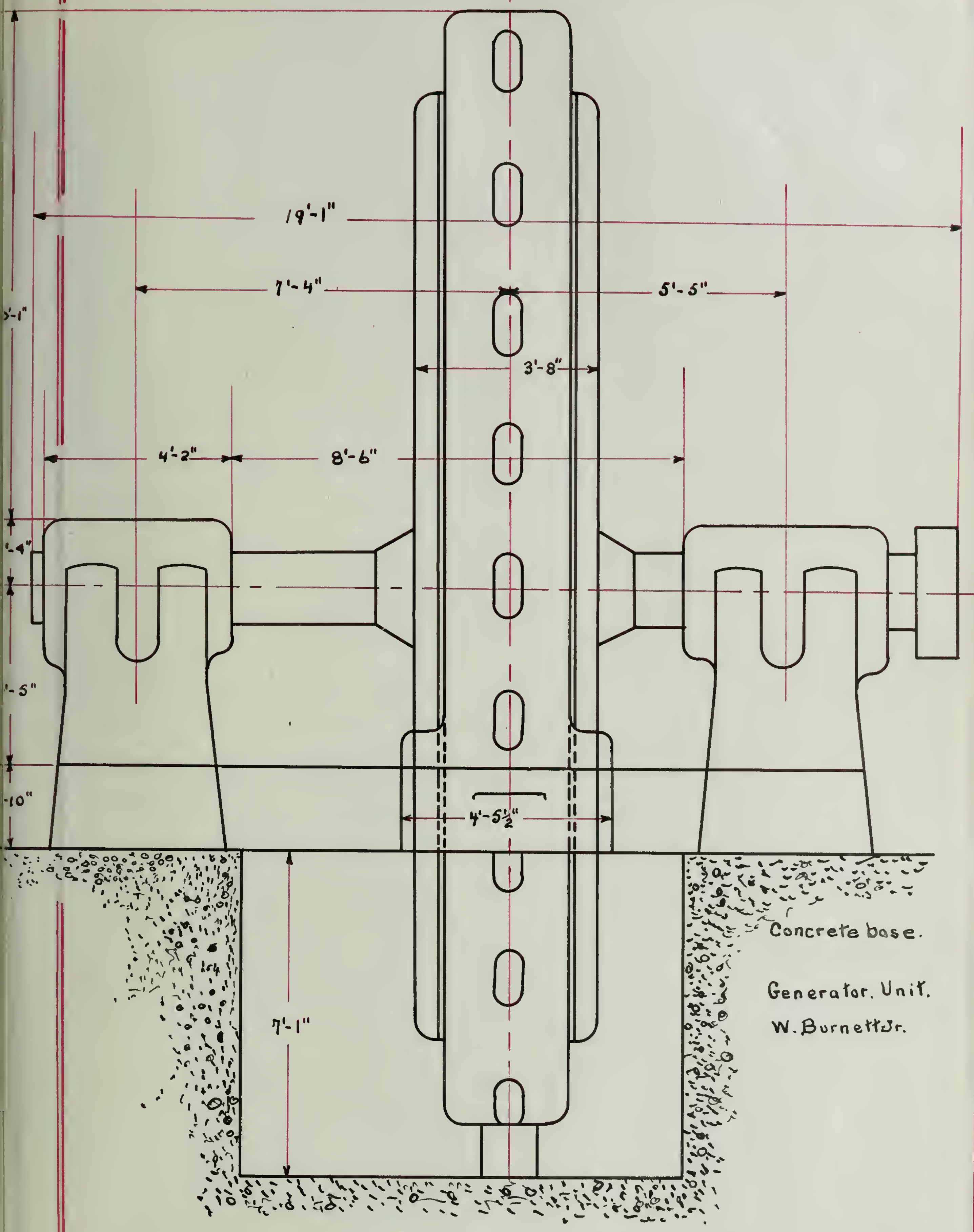
For practically 9 hours in the day during the winter months there is a load of 15,000 K.W. For 6 hours during the day there is approximately 10,000 K.W. being used and for the remaining 9 hours the full capacity of the station is needed. From the above figures it would seem that units of 5000 K.W. capacity would be best. Two units then could carry the 10,000 K.W. load and the third unit could be paralled for the 15,000 K.W. load. During the peak load all the machines would have to be used. Also note that if for any reason there should be one of the machines put out of service during the heavy winter peak load the other five units could carry the load without heating up very much. Each unit would only be overloaded 8 %. However this will be increased when the plant takes on the maximum designed capacity, of 30,000 K.W.

The electrical units that were choosen for this purpose are,

6 -- General Electric Alternating Current Generators,44-164-5000-6600. This means that the number of poles on the machine is 44,the speed per minute is 164 revolutions,the capacity of the machine is 5000 kilo-watts and the voltage that will be generated is 6600 volts. The drawing and the principle dimensions for this unit can be found on the following page.

The outside dimensions of the generator are 28'-8" by 19'-1".


Generator Unit.
6600 volts 164 R.P.M
3phase 60~ 5000 K.W.
Illinois River Co.,
Wm. Burnett Jr.
16'-8"
5'-3"
7'-2"
27'-6"
22'-11" dia
6'-0"
3'-4"
2½" bolts
10'-0" long.
Concrete Foundation
Pit.
9'-0"
9'-0"
10'-9"
10'-9"
12'-0"
12'-0"
2'-4"
2'-4"
28'-8"


19'-1"
7'-4"
5'-5"
3'-8"
4'-2"
8'-6"
4'-5½"
7'-1"
'-1"
'-4"
'-5"
-10"
Concrete base.
Generator. Unit.
W. Burnett Jr.

The foundation is to be made of solid concrete which rests on the same bed rock as the dam.The above construction will prevent any vibration. The diameter of the generator housing is 22'-11" and it will rise 16'-8" above the floor line. The concrete pit is 7'-2" deep,and gives good conditions for bringing out the leads that run to the low tension oil switch. The main frame is held by four steel foundation bolts 10'-0" long and $2\frac{1}{2}$" in diameter, with a plate of steel 1" thick and a foot square. The bearings are 4'-2" long and are to be lubricated by a high pressue oil pump. The hollow nickel steel shaft is 11 inches in diameter and is designed with a big safety factor.

The following is the cost of the generators and of their installation.

Cost of one generator $2413 + 4.69 \times$ kva.

$2413 + 4.69 \times 5000$ \$25,863.00.

The cost then of six units is \$25,863 x 6 = \$155,000.00. This cost does not include the accessories.

Exciter Units.

The two exciter units are direct current and are driven by separate horizontal turbines. The machines will run at 249 r.p.m. have a capacity of 450 kilo-watts and deliver 250 volts to the bus bars. From this bus the main units will be excited. The remote control will make it possible to start the machines from the operating room and bring them up to the required voltage then a Tirrell regulator will be thrown in and this will keep the voltage constant. In case that either one of these units should break down when the load was at a maximum there is to be a motor-generator set that can be put into service. This will have the same capacity as one of the units. All the exciter units will be connected so that they can operate in parallel and if one unit is cut out the other two can carry the

load. A drawing of the exciter unit giving just the principle dimensions is found on the following page.

The switch-board panel that is given over to the exciter units contains one voltmeter and two ammeters. The voltmeter is arranged so that it can read the voltage of each machine,and the ammeter is to read the total current that is being used for excitation purposes. An intergrating wattmeter will read the consumption of power taken from these units.

Cost of exciter and the motor-generator set.

Cost of one unit 12.08 x K.W. - 383.

12.08 x 450 - 383.

$5,042.00.

For the cost of two machines then the price will be $10,084.00

For the auxillary motor-generator set the additional cost of,

Alternating Induction , motor cost 116 + 4.72 x h.p.

116 + 4.72 x 710=$3466.00.

Cost of the direct current generator $5,042.00

Total cost of motor-generator set $8500.00

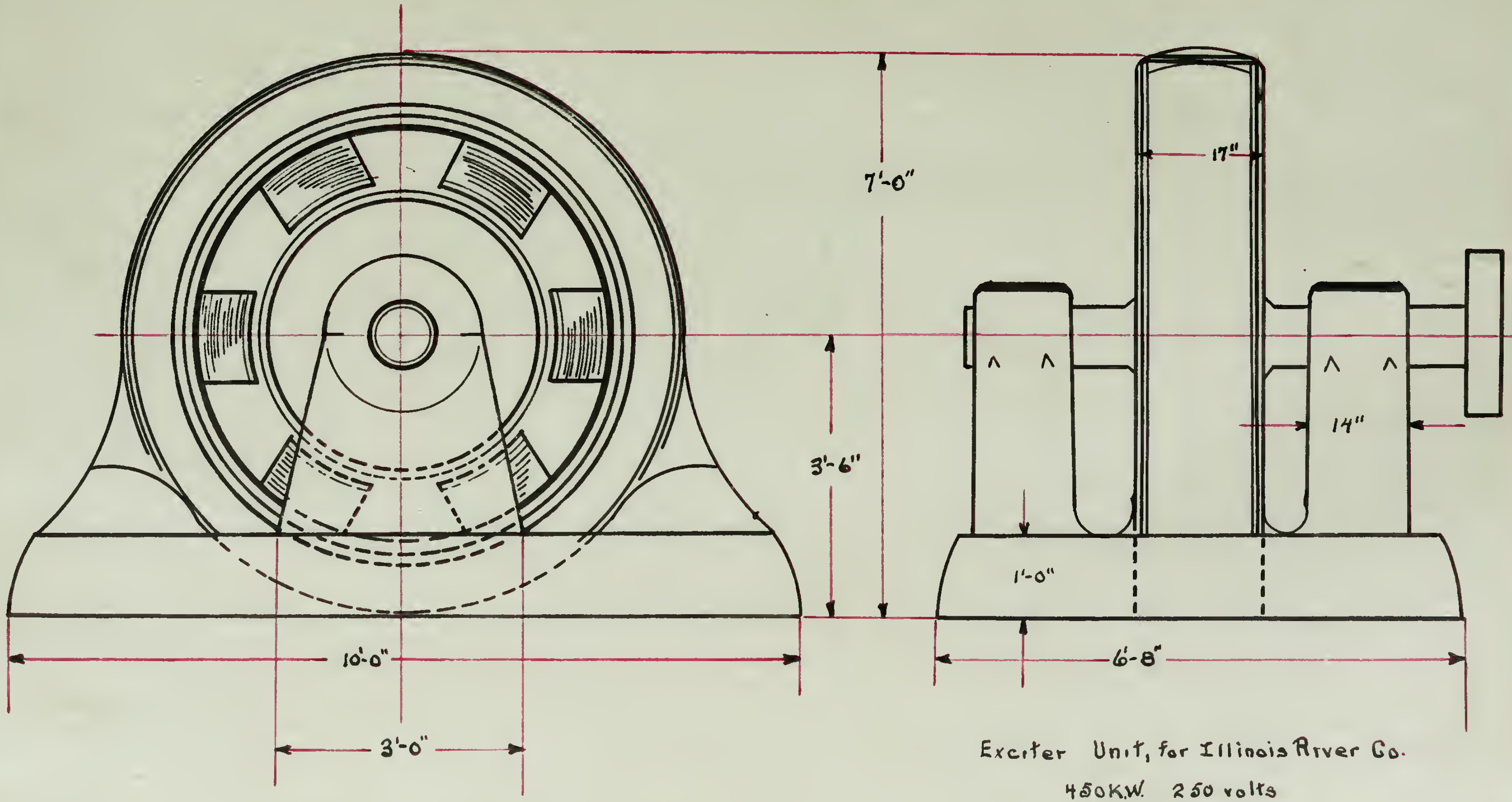
Then the total cost for all the exciter units is $18,584.00.

The floor space neededfor these units is 10 feet x 7 feet. The foundations for this installation is to be made of solid concrete 10 feet deep and massive enough to keep down excessive vibrations.

Transformers.

The transformers are to be three phase ,5000 K.V.A. The method of cooling will be arranged for by letting the water flow thru from the reservoir out into the tailrace. The low tension side will be delta connected and the high tension side grounded wye. The voltage transformation will be from 6600 to 66000 volts.

The cost of one transformer = $6,300.00.



Exciter Unit, for Illinois River Co.
450 K.W. 250 volts
249 R.P.M.
Wm. Burnett Jr.

The cost then for seven is $47,600.00 An extra transformer is to be kept on hands so that it can be used to replace any one of the others that may burn out.

Oil Switches.

The oil switches will be separate units. There will be six on the high tension side and six on the low tension side. They will be operated by a small motor controlled from the remote switch-board room. In using both oil switches on the low and high tension sides it makes it possible to have the generator feed thru the low tension bus bars and out to the transmission line without having to go thru the transformer that is used for that units. Also it can be so arranged that the generator and the transformer can be used as one unit and synchronized on the high tension bus. This gives a very flexible system which is needed in case of a break down of any unit in the plant.

Cost of the oil switches high tension	$10,000.00
Cost of the oil switches low tension	$ 5,000.00
Total	$15,000.00.

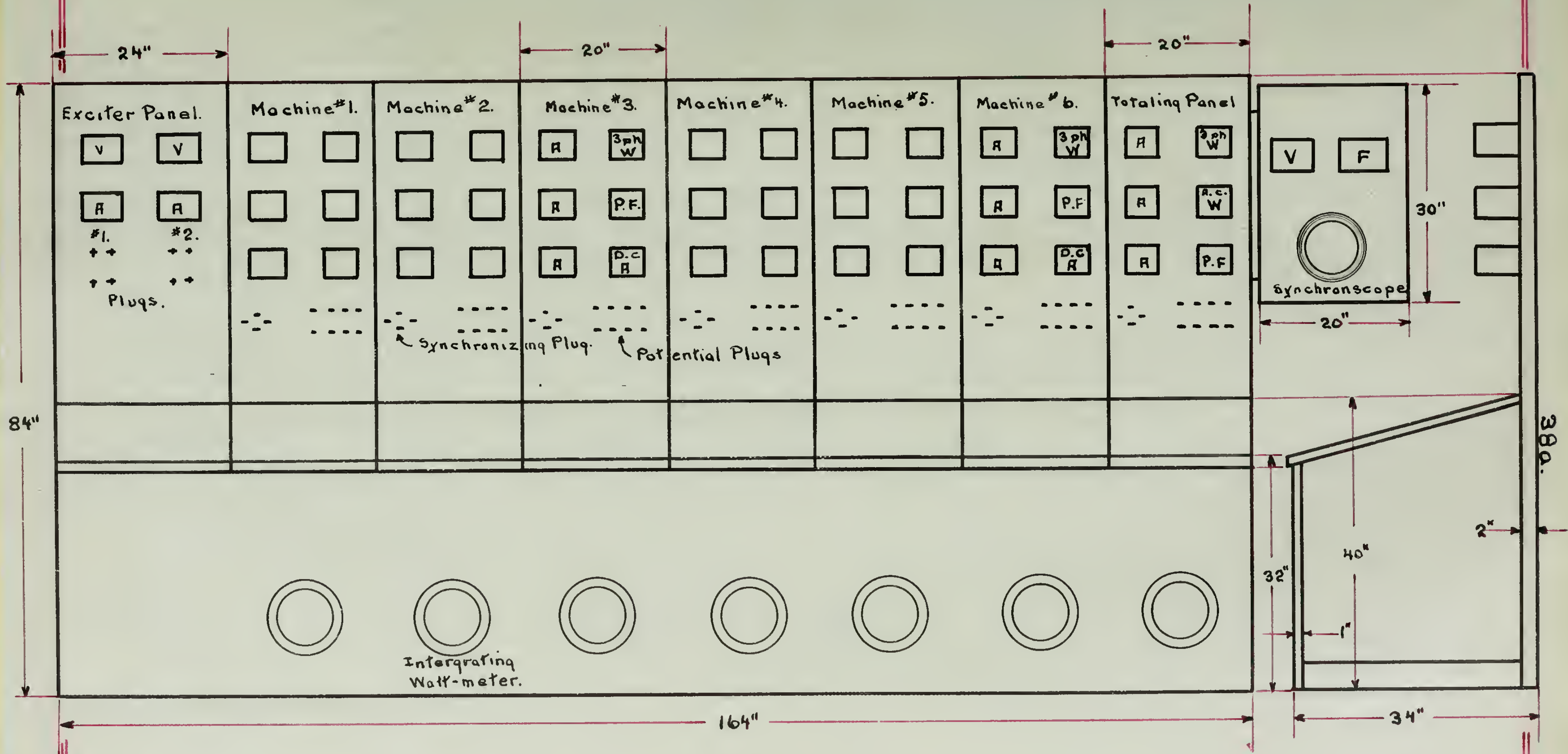
Control of the circuits.

The switching will be accomplished by means of remote control. Each generator will first have its leads brought out thru three series limiting reactances. From these the wires will go thru the disconnecting switches and then to the oil switches. This oil switch will be operated by a motor which can be controlled form the switch-board room. From the oil switch the leads will go thru another set of disconnecting switches and then to the low tension bus. In having the second set of disconnecting switches the oil breaker can be worked on at any time even tho the low tension bus is alive. However there will also be another disconnecting switch in the low tension bus which will be called a sectionalizing switch,so

that the generator can feed right thru the transformer to the high tension bus. On the following page is shown a complete wiring diagram of one of the main units. There will be three ammeters in the set up and these will be connected by the two transfotmer method of measuring current. The capacity of each meter will be from 0 to 200 amperes. A three phase watt-meter will measure the output of the unit. A power factor meter will denote the angle of lag of the current behind the voltage. On the following page is shown a drawing of the arrangement of the meters on the remote control board. At the bottom of the panel there will be placed an inter-grating watt-meter from which the output of the generator can be read. The voltage of each circuit can be read by using the potential plugs and only one voltmeter will be used,which will be placed on a swinging arm at the end of the panels.

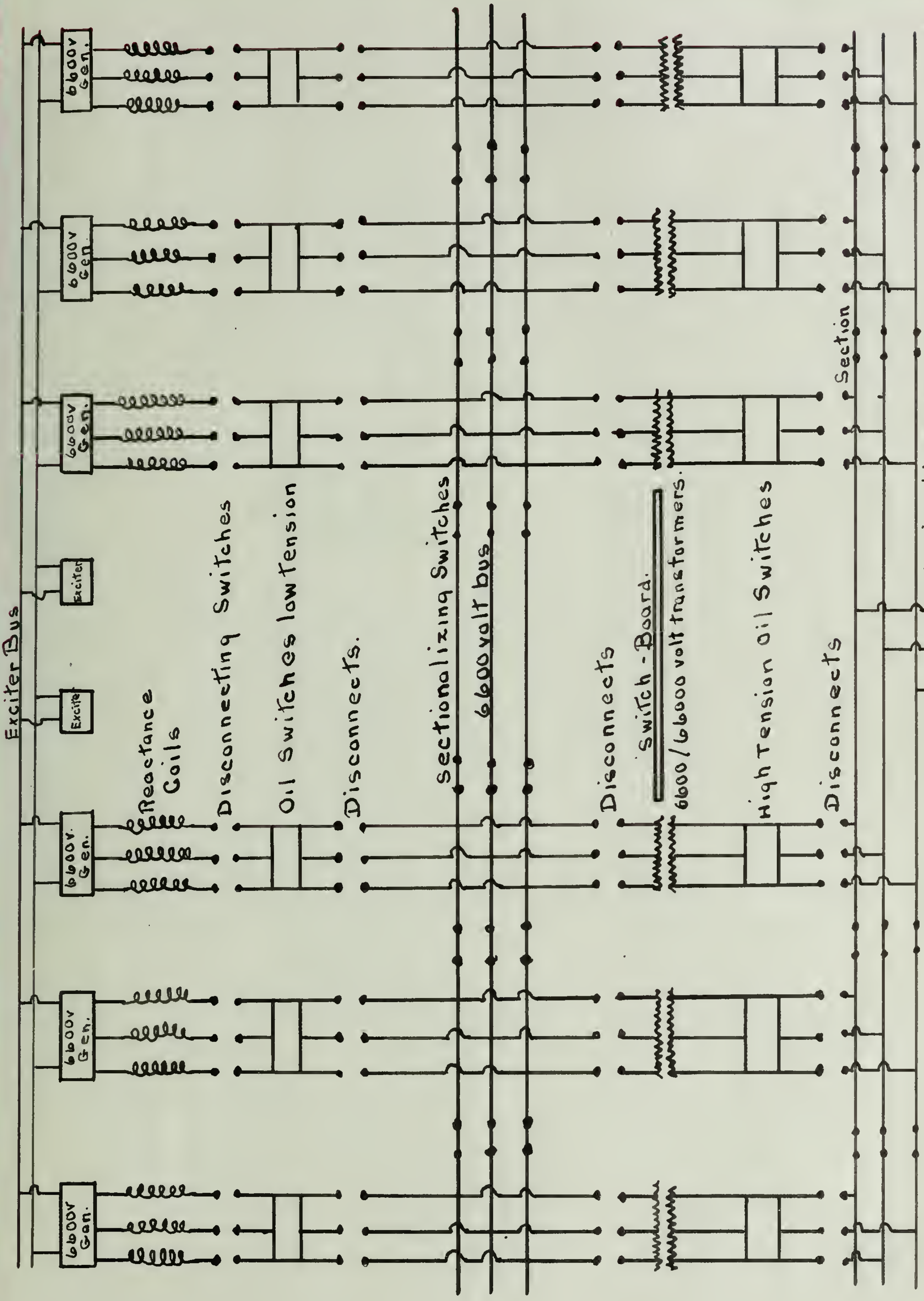
General wiring layout of the system.

The wiring diagram of one of the units has been given on one of the preceeding pages. This gives the description up to the low tension bus. There are six section of the low tension bus and it is possible to divide it up and synchronize on the high tension side. A diagram of the principle connections are found on the following page. The leads on leav-ing the low tension bus go thru a set of disconnecting switches and then thru the transformer to the high tension bus. The high tension bus is also sectionalized. There will be two outgoing lines carrying 66000volts. They will normally operate in parallel but in case of trouble the load can be shifted from one side to the other. This will enable the company to give good service and reduce the line loss when the two are in parallel. On the two outgoing lines will be placed the choke coils and the lightning arresters,with their charging device. The aluminum cell type of arrester will be used and will be of 38?00 volt capacity. On one of the following

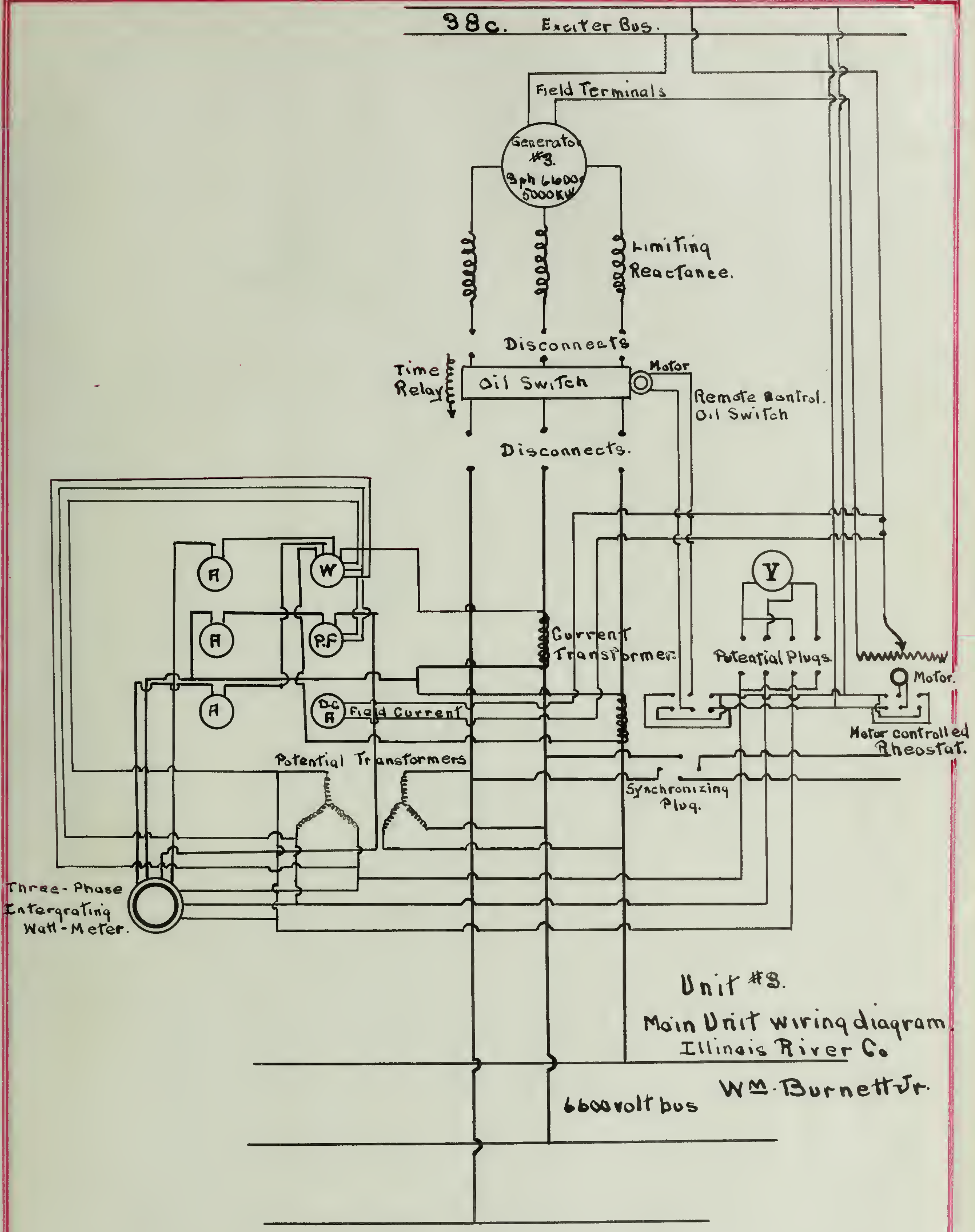


Remote control switch-board.

Wm. Burnett Jr.



Principle diagram of connections.
Illinois River Co.
Wm. Burnett Jr.



Unit #3.

Main Unit wiring diagram
Illinois River Co.

Wm. Burnett Jr.

pages is a drawing of the arrester and the connections.

The cost of this protection is $20,000.00.

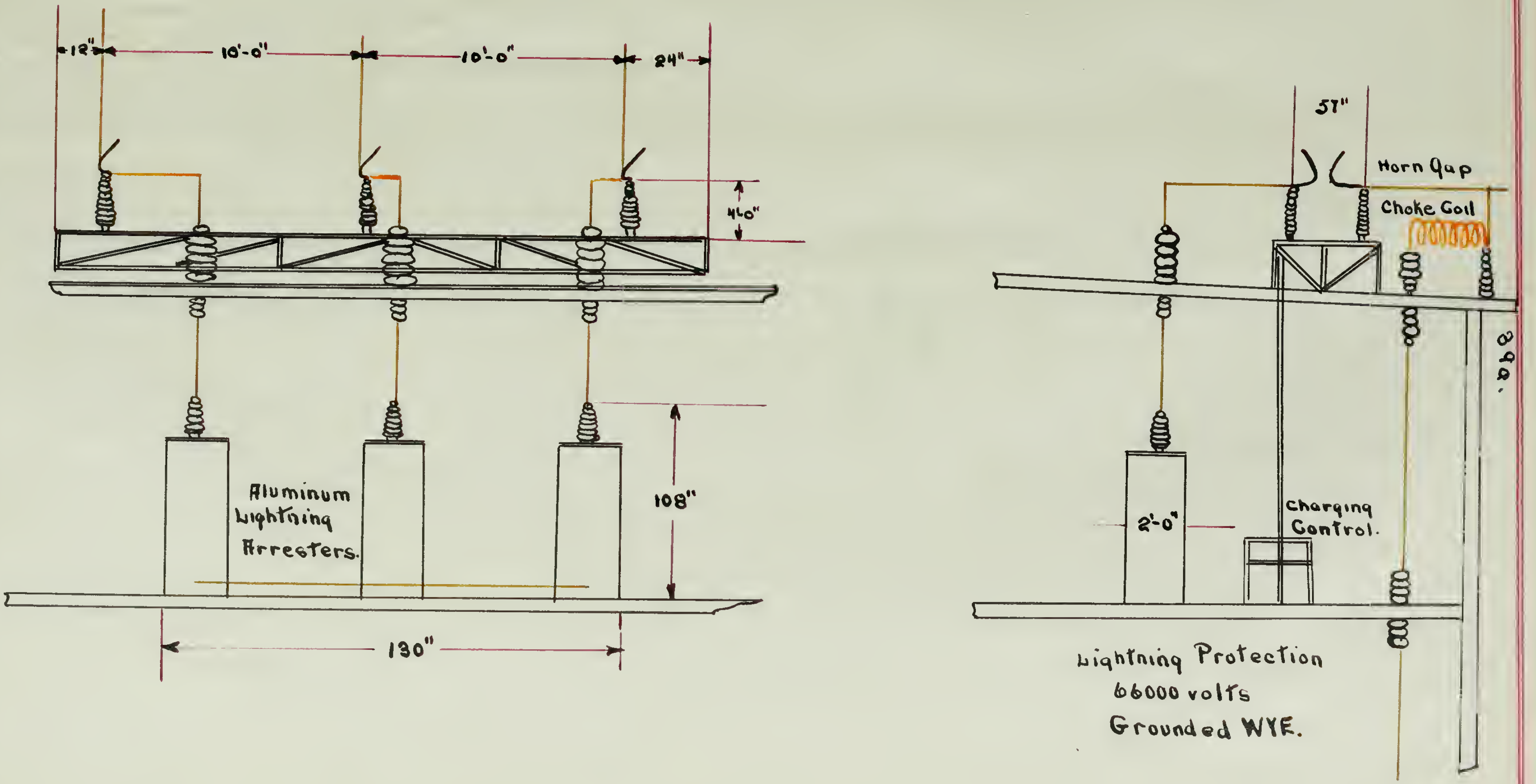
Power House.

The power house will be 235 feet long and 60 feet wide. The generator units will be placed three at one end and three at the other end. The exciter units will be placed in the middle with the auxiliary motor-generator set in front of them. The switching side of the plant will be constructed in four stories. The first floor will contain the reactance coils and the low tension oil switches. The second floor will hold the transformers. In the third story the switch board and the high tension switching apparatus will be stationed. The top floor will be given over to the lightning protection and the store rooms.

A fifty ton crane will span the generator room and will be able to lift ary piece of the machinery. This will be electrically operated and will run the full length of the building. The transformers will be set on small cars so that in case of trouble they can be disconnected and run out into the main room where the crane can lift them. At one end of the station there will be left space so that a flat car can be backed in and the crane can load or unload any piece of machinery.

The foundation of the power house will be made of solid concrete. In the upper portions reinforced concrete will be used. The transformer room will be 20 feet x 20 feet and will be divided into seven sections so that each section will provide for one of the three phase units. Six transformers will always be in use while the seventh will be held in reserve.

Each turbine chamber will be controlled by a gravity gate so that if any trouble or repairs need be made the pit can be drained by shutting the gate. The tail race flumes will be faced with neat cement and shaped so that they will give a discharge without eddy currents.



Lightning Protection
66000 volts
Grounded WYE.

Cost of power house.

Excluding the minor calculations as they would require too much space the cost of the power house comes down to this,

26,000 cubic yards of foundation concrete	@ $6.00	$155,000.00.
3,015 cubic yards of reinforced concrete	@$10.00	30,150.00.
Building steel,windows,I beams and other accessories		60,000.00.
Total cost of power house		$245,150.00.

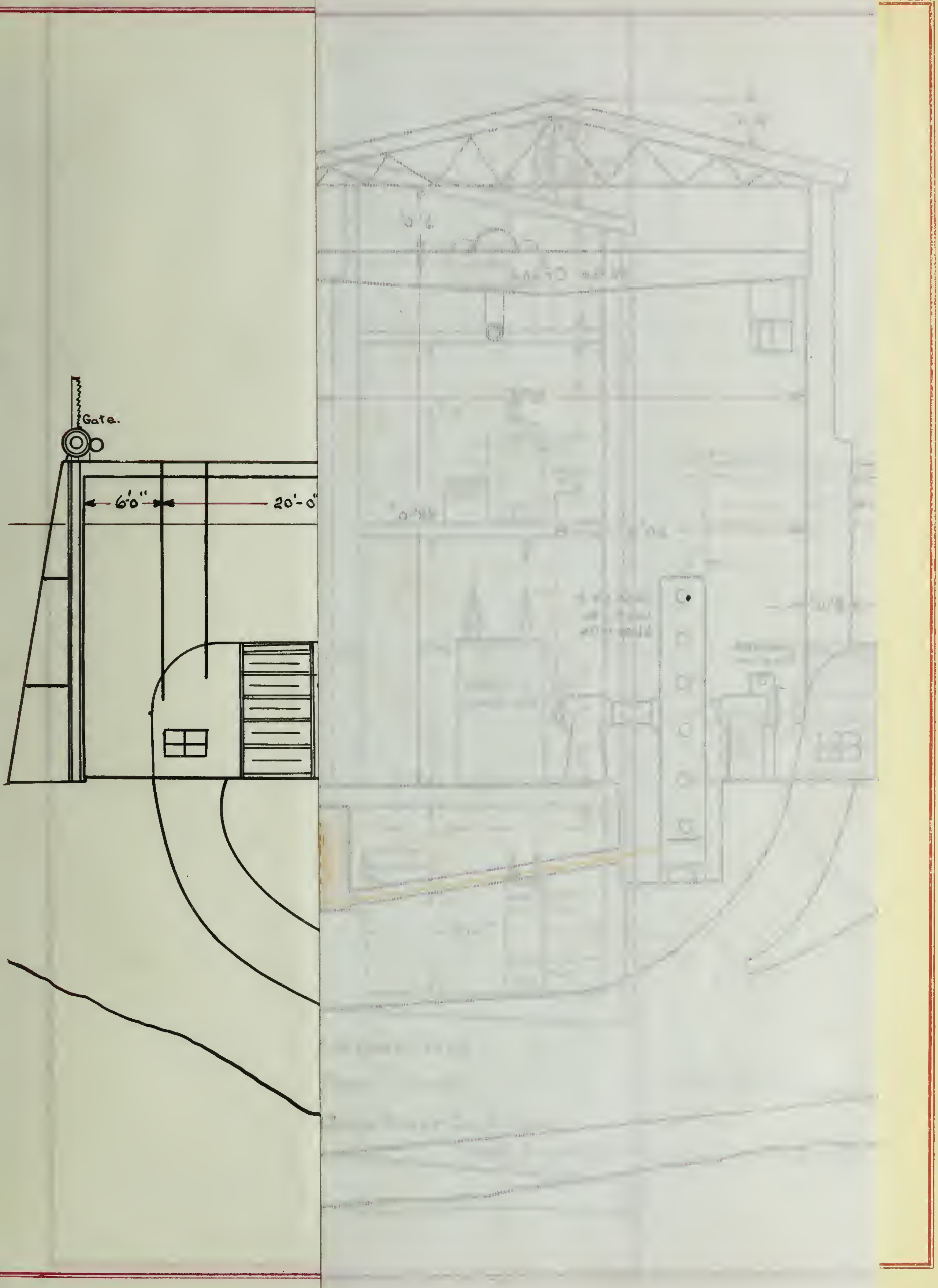
On the following page is shown a sectional view of the power house and the arrangement of the main units and other electrical apparatus.

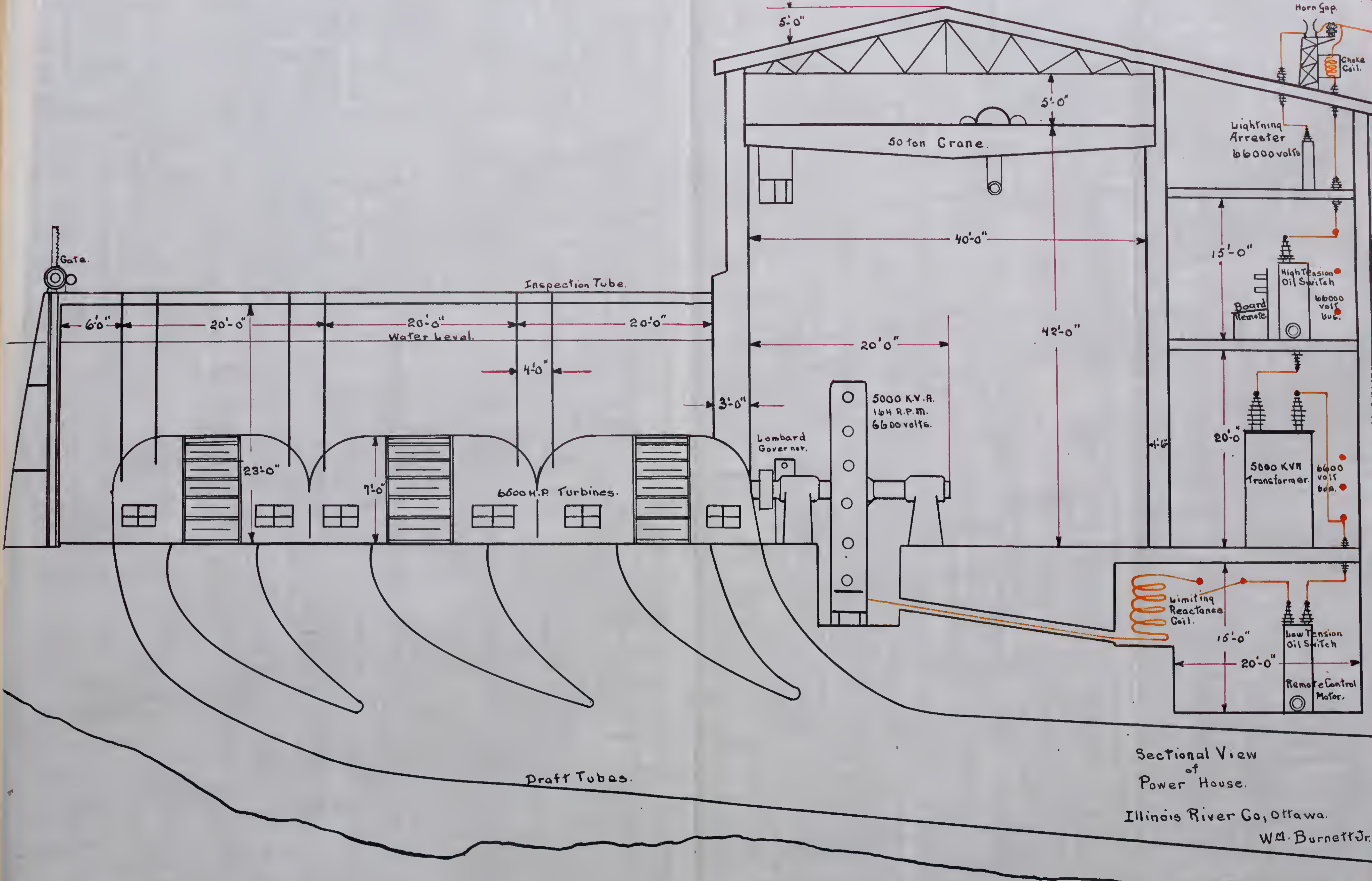
Transmission line.

The next question that comes up is the transmission of power from this location. It will be necessary to run a line about 100 miles long from Ottawa thru to Decatur. The present conditions show that it is impossible to use power near the plant and the first object of this design was to supply power to the McKinley system within a 100 miles of this plant. This power is to be used for lighting purposes manily,and some for power work. However the plant is to furnish current for the street railways in the various towns mentioned on a preceeding page. All these towns mentioned will be supplied with power and also a few small places will be allowed to tap into the line.

The installation of this transmission line will allow all the towns in the central part of Illinois to be given service and the cost of the upkeep in several plants that are operating under steam at present,will be eliminated.

The nature of the ground over which the line will run is very level. It will not be necessary for the McKinley people to buy a new right of way for at the present time they have one from the towns mentioned above. This will mean a great saving in expense for line construction. The ground


Gate.
6'-0"
20'-0"



Sectional View of Power House.

Illinois River Co, Ottawa.

Wm. Burnett Jr.

is the best kind in which to set poles being a layer of black soil on top of yellow clay. Another good thing about the ground on which the line will be constructed is that it has good drainage and this will mean dry land with very little rot to the pole line.

The right of way will be along the interurban tracks and therefore it will always be an easy matter to get at any trouble on the line. In coming into the cities where substations are located it will not be necessary to buy expensive land because the ground is already in use. The towns are in most cases not so large that great care has to be taken in the direction or the parts of town that the line is run thru. There will however be laws that will limit the line construction as to safety and other minor details. This line will be double circuit supported on steel towers. On top of the tower there is to be a $\frac{1}{2}$" stranded steel cable run for lightning protection. On the following page a drawing of one of the towers can be found. The height of the lowest wire above ground will be 40 feet. This height is choosen mostly because it is common practice and works very well. The lower cross arm will be 20 feet long and the upper one will be 1[illegible] feet long. The distance between wires is to be 6 feet. The ground wire will be placed 8 feet above the upper cross arm so that the vertex of an angle of 90 degrees if put at this point will have lines extending from it that will include all the wires. It is said that the ground wire will protect all the wires that are inclosed within this space. The tower will be made of structual steel, latticed so as to obtain the strength needed. The base will be four feet square and set in a suitable foundation of concrete. The distance between towers will be 550 feet as this is the limiting stress that can safely be put on the conductors, that are to be used.

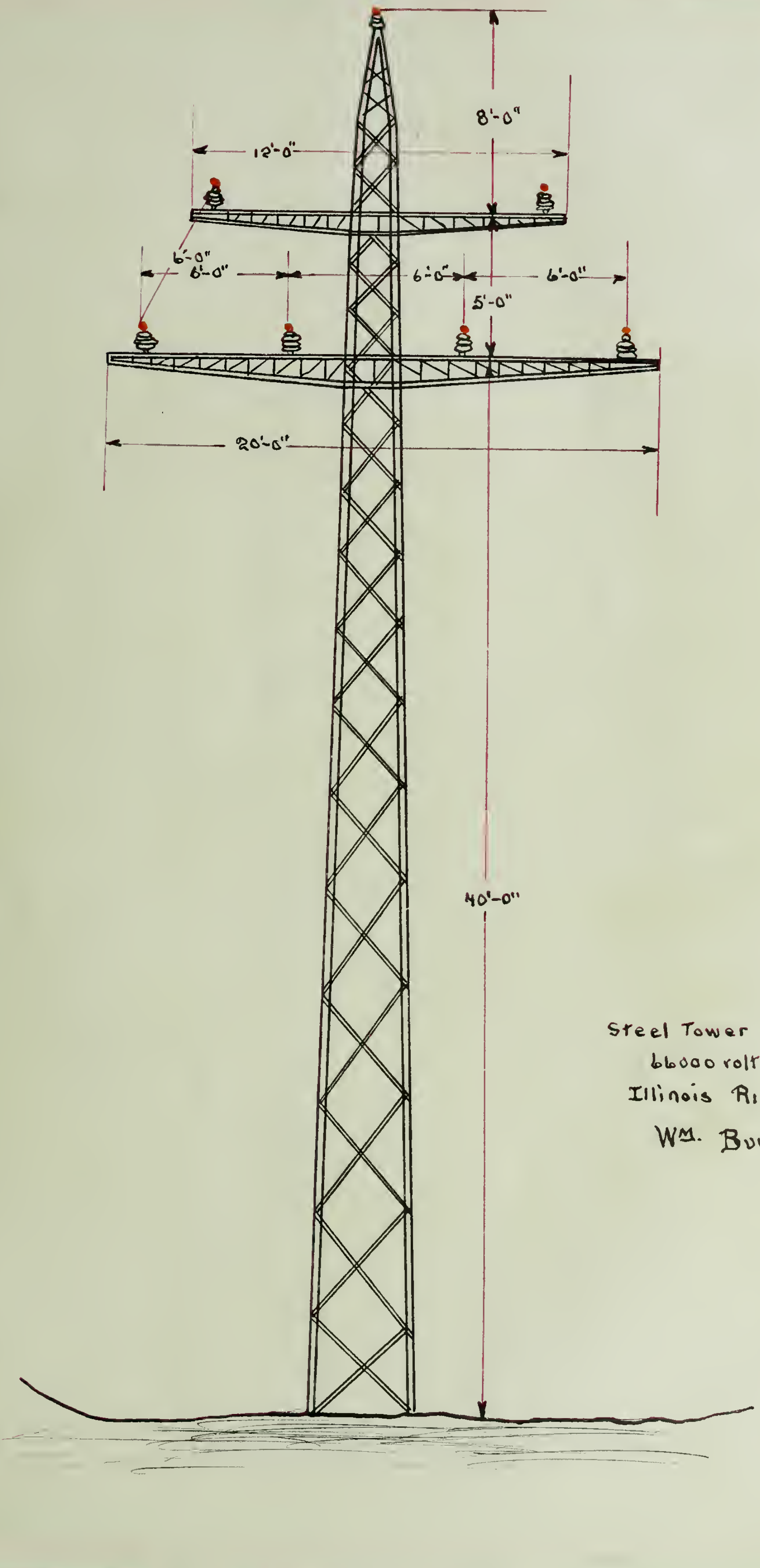
Cost of the steel towers.

Cost of insulators, pin type six for each pole	$12.00

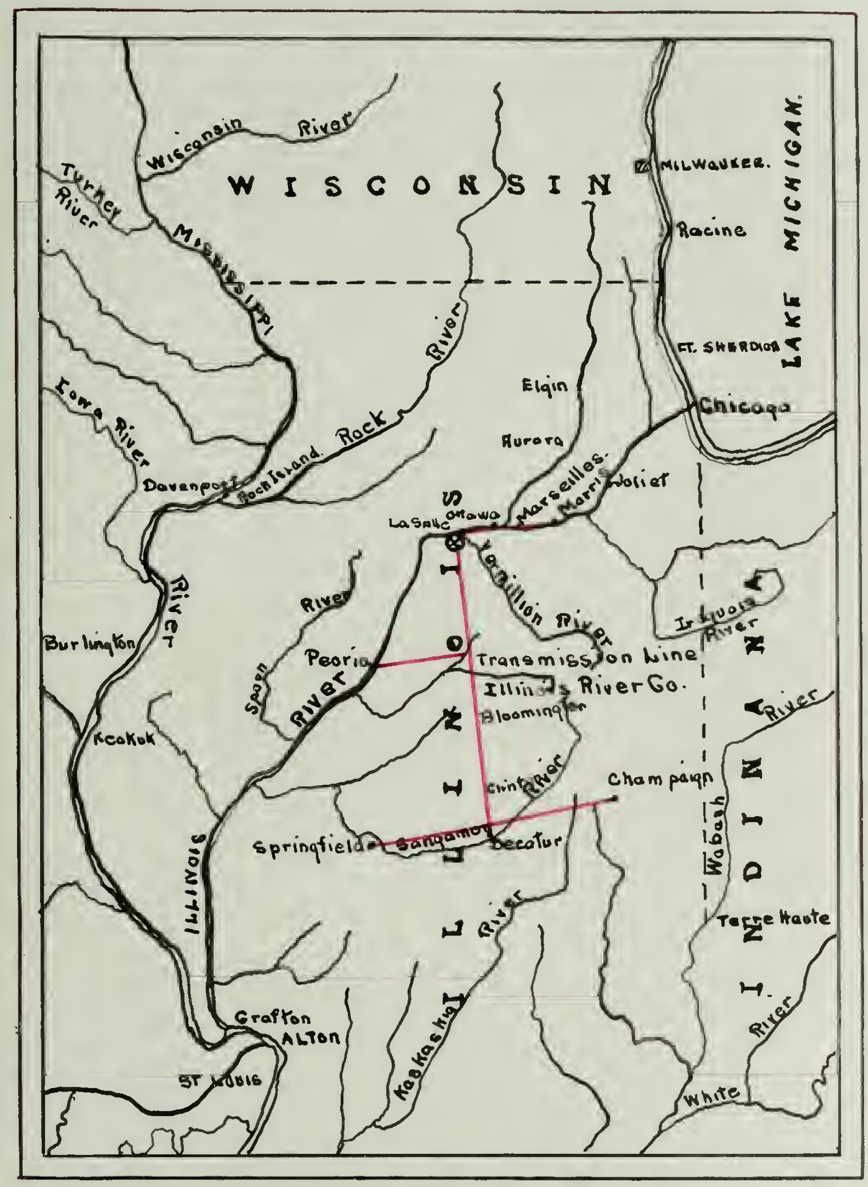
Cost of the steel and its erection per pole	$60.00
Cost of the foundation and its installation	$50.00
Total cost per pole	$122.00.

Then the cost of the transmission for the 100 miles will be,

960 towers @ $122.00	$117,000.00.



Steel Tower Construction.
66000 volt - 2 circuit.
Illinois River Co.
Wm. Burnett Jr.



Illinois River Company.

Transmission Line.

Wm. Burnett Jr.

Earning capacity.

The following conditions were taken from good references and these give the average cost of such a plant. A through discussion was taken up in the March number of the A.I.E.E. by M.E. Cooley in which he relates the various returns on certain items for the construction of the plant. The contractors profit is to be 10%. There is .2% for the investigation of the development and 2% is to go to the promotor. The engineering concern will receive 5% for its share of the work. Half of the money that will be expended will have to be used up before the job is completed and this is figured at 6% interest. This is considering that it will be two years before the work is completed. Then

15% is allowed for the contractor and the engineer.

3% for the entire amount of money used on the construction.

10% for contingencies that are apt to come up.

.2% for the investigation of the site.

2% for the promotor's work.

.5% for taxes, and .5 % for insurance.

6% for the interest that will be the return on the investment.

Depreciations.

3% for the turbines, generators, switchboard, building, etc.

3% for the transmission line including repairs.

1% for obsolescence.

11.0 % then is the amount that will be earned on the investment. The operating expenses will add another per cent to this bringing the total up to 12.0 per cent. The cost per kilo-watt of installation is $134.00. From the load curves it is calculated that 108,200,000 kilo-watt-hours can be sold a year. This gives a cost when including running charges of .5 ¢ per kilo-watt hour. This is the cost that will set the price

of power.

Kelvin's Law.

The power will be distributed in this way along the line. 30,000 K.W. will leave the station at 66,000 volts, and will be transmitted 40 miles. At the forty mile point a load of 8,000 K.W. will be consumed. Then 22,000 K.W. will be transmitted for 20 miles. At this point 3500 KW. will be used. The rest will be sent to Decatur a distance of 40 miles from the last point. The first section of the line is from Ottawa to the Peoria taps. This cable will be 250,000 cir-mils, having 9 ohms resistance per wire, and .57 inches in diameter. The wire from the Peoria taps to Bloomington is to be # 0000 cable having a resistance of 5.2 ohms per wire and .528 inches in diameter. The conductors from Blooming ton to Decatur will be # 000 copper cable having a resistance of 13.2 ohms and .47 inches in diameter. The lines that are shown on the map, from the main line to Peoria, and from Decatur to Champaign and Springfield are all ready installed and the voltage will be reduced to 33,000 volts for these lines.

Section from Ottawa to the Peoria taps, 40 miles.

30,000 k.w. double circuit line, length 217,350 feet, 9 ohms per wire.

Using 250,000 cir-mil cable, 19 strands, .57" in dia. 775# per 1000 feet.

Power 1.73 E I cosa. Current I full load = 154 amperes.

For 4 hours in the day the full load current is flowing and the other 20 hours only half of this amount.

$154^2 \times 9 = 213000$ watts.

$77^2 \times 9 = 53200$ watts.

The I^2R losses then for one year,

$213 \times 4 \times 365 = 311000$ K.H.W.

$53.2 \times 20 \times 365 = 388000$ K.W.H.

Total loss = 699000 K.W.H. @ .45 = $3500.00

Assuming 8 % interest and depreciation on copper in the line then,

Cost of the copper for this line per wire, \$ 203,000.00.

775 x 217.3 x .08 x .20 = \$2700.00, interest and depreciation on the cost.

This makes the cost of copper per year and the I^2R losses as nearly equal as the standard sizes of wire will allow.

Section from Peoria taps to Bloomington, 20 miles.

22,000 K.W. .85 P.F. resistance per wire 5.2 ohms. Dia. of wire .528"

658 # per 1000 feet. Using # 0000 stranded cable.

Loss per wire in I^2R for one year **\$ 1090.00.**

Interest and depreciation on one wire for a year \$ 1140.00.

Cost of six wires for this distance when 1140.00. is 8% \$85,500.00.

Section from Bloomington to Decatur, 40 miles.

18,500 K.W. at .85 P.F. resistance per wire 13.2 ohms. Dia. of wire .47"

520 # per 1000 feet. Use stranded cable # 000.

Loss per wire in I^2R for the year **\$1970.00.**

Interest and depreciation on one wire for one year \$1060.00.

Cost of six wires for this distance when 1060.00 is 8 % \$136,000.00.

Total cost of copper for the line	First section	\$203,000.00.
	Second section	85,000.00.
	Third section	136,000.00.
	Total	\$424,500.00.

3 % sag was allowed thru out the calculations, for the wire.

The I^2R losses for the year costs

This completes the work outlined for this development. The results obtained here compare very favorable with some of the best reference data, and I think that the money allowed for the construction for such a plant is a fair estimate for this undertaking.

Summation of the costs.

Cost of flooded Illinois valley	$687,400.00.
Cost of Fox valley land	76,700.00.
Moving railroad tracks	41,210.00.
Cost of dam	239,350.00.
Damage to property	25,500.00.
Cost of ice fender	10,000.00.
Cost of goverment locks	95,000.00.
Cost of lumber for forms	60,000.00.
Cost of tail race excavation	263,500.00.
Cost of turbines	217,000.00.
Cost of generators	155,000.00.
Cost of turbines governors	18,000.00.
Cost of exciter units	18,584.00.
Cost of transformers	47,600.00.
Cost of oil switches	15,000.00.
Cost of remote control apparatus	30,000.00.
Ligthning protection	20,000.00.
Cost of power house and details	245,150.00.
Cost of transmission line excluding copper	117,000.00.
Cost of power house copper and insulators	125,000.00.
Assumed cost of transmission line copper	500,000.00.
Ground wire	18,400.00.
Contractors share etc, 27.2 %	823,000.00.
Interest on above amount of money for 2 years 3%	231,000.00.
Total cost	$4,079,000.00.
Subtracting $75,500.00 to get the true cost of line copper	4,003,500.00.
I^2R losses each year, transformers and line	50,040.00.
Money on which the 12 % will be earned	$4,003,500.00.